

METAL FINISHES MANUAL

*For Architectural
and Metal Products*



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National
Association
of Architectural
Metal
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National
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& Miscellaneous
Metals Association

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Introduction To Metal Finishing

NAAMM/NOMMA AMP 500-06

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INTRODUCTION TO METAL FINISHING

The variety of finishes used on architectural metals, like other aspects of building technology, becomes increasingly complex. Recognizing the need for organized information on this subject, the National Association of Architectural Metal Manufacturers (NAAMM) published the first edition of this Manual in 1964. A second edition was published in 1969, a third edition in 1976, and a fourth edition in 1988. In response to the continuing demand for the Manual, this edition, containing still further revisions, is being published jointly by NAAMM and the National Ornamental & Miscellaneous Metals Association (NOMMA).

The scope and nature of this edition are the same as those of the former editions, but all of the contents have again been carefully and critically reviewed. Obsolete data has been deleted, errors have been corrected, references to standards and supplementary sources of information have been updated, and the text has been extensively revised to reflect current practices.

The Manual consists of five chapters and an Introduction to Metal Finishing, which briefly explains the applicability of the various finishes for architectural applications. The first four chapters cover finishes for the specific architectural metals, aluminum, the copper alloys, stainless steel, and carbon steel and iron respectively. Chapter 5 covers applied coatings used on all metals.

It is still the prime purpose of the Manual to provide the architect with essential information about the many finishes available, and to assist him in selecting and properly identifying them. It is intended as a reference handbook, dealing briefly with all of the finishes commonly used, but not attempting to provide complete information about them. With the many new developments constantly occurring, a small volume such as this can serve only as an introduction to this very broad subject. For those desiring more comprehensive information, numerous references to supplementary sources are provided.

The production of satisfactory finishes on architectural metal requires teamwork and cooperation among the metal supplier, the fabricator, the

finisher, the architect and the contractor. It is not the sole responsibility of any one of these parties. The architect must understand the characteristics and limitations of the many finishes available, so that he may select those which are proper and appropriate for his purposes, and he should be able to clearly define his requirements. It is the responsibility of the supplier and fabricator to interpret these requirements sympathetically, to furnish the appropriate alloys, and to see that all necessary steps are taken to produce the desired effects.

The contractor must see that the finishes supplied are handled and installed with care, and are properly protected after installation. A satisfactory end result is the common aim of all parties, but a lack of mutual understanding can easily result in dissatisfaction. One of the aims of this Manual is to minimize the likelihood of such deficiencies by encouraging a better common knowledge of the subject, for the benefit of all concerned.

General Classification of Finishes

All of the finishes commonly used on the architectural metals can be classified as one of three principal types:

Mechanical Finishes, which are the result of physically affecting the surface of the metal by some mechanical means. This means may be the forming process itself, or a subsequent operation performed either before or after the metal is fabricated into an end use product.

Chemical Finishes, which are accomplished by means of chemicals, and which may or may not have a physical effect upon the surface of the metal.

Coatings, which are applied as finishes, either to the metal stock or to the fabricated product. These coatings may be either:

- a) Formed from the metal itself by a process of chemical or electrochemical conversion, or
- b) Formed by the application of some added material.

The relative importance of the three basic types of finish varies with the different metals. They are all used extensively on aluminum, but on carbon steel and iron, the coatings are far more important than either mechanical or chemical finishes. The copper alloys are commonly subject to both mechanical and chemical finishes. On stainless steel the mechanical finishes are the common standard, while chemical finishes and coatings are infrequently used. Table 1 - Comparative Applicability of the Various Types of Finishes provides an overall view of the extent to which the various types of finishes are normally used on the different metals.

Because many of these finishes are not distinctly or uniquely suited to any one metal alone, and usages overlap considerably, the subject has not been found to lend itself to a neatly compartmented treatment, arranged either by metals or by finishes. It has seemed advisable, therefore, to classify the bulk of the discussion according to metals, treating under each metal not only those finishes which are uniquely its own, but also the mechanical and chemical finishes as applied to that metal. This necessarily involves some repetition of basic information regarding the more common finishes, but these overlaps seem justifiable in the interests of providing optimum clarity and minimizing the need to refer from one chapter to another. With certain types of applied coating, however, the chief concern centers on the coating itself, rather than on any particular substrate, and it has seemed advisable to discuss such finishes under the heading of Applied Coatings, rather than identifying them with any one metal. Thus the typical mechanical and chemical finishes, as well as the unique coating finishes for each of the metals are discussed in Chapters 1 through 4 under headings identified by the metals, along with the designation system used for denoting these finishes. The organic, laminated, and vitreous coatings, however, being generally applicable to several metals, receive separate consideration in Chapter 5.

The Function and Source of Finishes

The function of metal finishes may be protective, decorative or both. A majority of the many surface treatments identified in this Manual as “finishes” are not, in fact, final treatments, but only intermediate steps in a finishing process. Many

are applied for protective reasons, some for reasons of appearance, and a few are simply cleaning processes. Usually several steps are required in preparing a metal surface for its specified end use condition. All of these steps are designated, in the terms of the trade, as “finishes,” though only the final treatment is actually exposed to use; the others are in fact simply preparatory treatments. This is often the case, for example, where compound finish designations are the general rule, as is explained in Chapters 1 and 2.

Only a few of the many finishes discussed are provided by the basic suppliers of the metal. In the main, these are the so called “as fabricated” finishes, which are usually the cheapest form of mechanical finish, and are available on all of the metals. Sheet stock of various metals is also available from the basic suppliers with several types of applied coatings, and aluminum and stainless steel sheet are supplied also with embossed and coined patterned textures. All of the other finishes are “process finishes,” and are applied by the manufacturer or fabricator of the product or by other companies specializing in finishing work. The quality of finish on many architectural products depends largely, therefore, on the skill of the fabricator or finisher rather than on the basic supplier, but the quality of the alloys furnished by the supplier is always a factor of prime importance.

Variations in Appearance; The Value of Samples

Visual appearance is often a major concern with metal finishes, and uniformity of appearance may be critical in many architectural applications. Some types of finish present no problems in this latter respect, while others are subject to slight variations. Uniformity of appearance is often dependent upon the alloys used, and in certain mechanical finishing processes it is affected also by the equipment and speeds used in the finishing operation itself. With the non ferrous metals, the achievement of a desired result often depends as much on specifying the right alloy as on choosing the right finish.

With rigid control of such variables, a high degree of uniformity can be achieved in any finish, but the architect should recognize that, except with opaque coatings, it is unrealistic to expect perfect uniformity of color and texture, particularly if the finish is provided by different parties or from different stocks of metal. For this reason it is rec-

ommended that the supplier or fabricator should always be consulted concerning critical requirements. The use of representative samples is usually advisable, too, as a means of describing requirements in applications where precise control is essential. When color is involved, at least two samples should be used, to define the permissible range of color.

The Choice of a Finish

A good working knowledge of metal finishes requires more than an understanding of the technicalities of their processes and the ability to designate them properly. If the architect is to specify them intelligently he or she will be concerned not

only with the esthetic effect desired, but also with their practical appropriateness and their relative costs as well.

These finishes vary considerably in the amount of labor they require, and consequently in their costs. Frequently money is wasted in the use of unnecessarily expensive finishes in locations where they can't be distinguished, and sometimes the choice of impractical finishes has needlessly complicated production processes, resulting in objectionable delays and expenses. On the other hand, some important jobs have suffered because of the unwise selection of a "low cost" finish or the arbitrary decision to avoid the relatively insignificant cost of a critical finishing operation.

Precautions

An attempt has been made in this Manual, by the prominent listing of "Precautions," to specifically point out the limitations inherent in certain types of finishes, and to indicate their most appropriate applications as well as their relative costs. It is hoped that the architect will find this information helpful in using all of the architectural metals more effectively.

**TABLE 1 - COMPARATIVE APPLICABILITY OF THE VARIOUS FINISHES
FOR ARCHITECTURAL APPLICATIONS**

	Type of Finish or Treatment	Metal			
		Aluminum	Copper Alloys	Stainless Steel	Carbon Steel and Iron
MECHANICAL FINISHES	As Fabricated	-----common to all of the metals----- <i>(produced by hot rolling, cold rolling, extruding or casting)</i>			
	Bright rolled	-----commonly used----- <i>(produced by cold rolling)</i>			Not used
	Directional grit textured	-----commonly used----- <i>(produced by polishing, buffing, hand rubbing, brushing or cold rolling)</i>			Rarely used
	Non-Directional matte textured	-----commonly used----- <i>(produced by sand or shot blasting)</i>			Rarely used
	Bright polished	-----commonly used----- <i>(produced by polishing and buffing)</i>			Not used
	Patterned	-----available in thin sheets of all metals-----			
CHEMICAL FINISHES	Non-etch Cleaning	-----commonly used on all of the metals-----			
	Matte finish	Etched finishes Widely used	Seldom used	Not used	Not used
	Bright finish	Limited uses	Rarely used	Not used	Not used
	Conversion coatings	Widely used as pretreatment for painting	Widely used to provide added color variations	Not used	Widely used as pretreatment for painting
COATINGS	Anodic <i>(See Ch 1)</i>	Traditional type of finish	Not used	Not used	Not used
	Organic <i>(See Ch 5)</i>	Widely used	Opaque types rarely used; transparent types common	Sometimes used	Most important type of finish
	Vitreous <i>(See Ch 5)</i>	Widely used	Limited use	Not used	Widely used
	Metallic <i>(See Ch 4)</i>	Rarely used	Limited use	Limited use	Widely used
	Laminated <i>(See Ch 5)</i>	Substantial uses	Limited use	Not used	Substantial uses

Chapter 1: Finishes For Aluminum

NAAMM/NOMMA AMP 500-06

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FINISHES FOR ALUMINUM

General

Aluminum is unique among the architectural metals with respect to the large variety of finishes used. Nearly all of the finishing processes discussed in this Manual, in fact, are not only appropriate but commonly used for this metal, whereas some of them are seldom if ever applied to other metals. Those used on aluminum include several varieties under each of the three major types of finishing processes, as shown in the following summary. The mechanical, chemical and anodic coating finishes, along with their descriptions and standard designations, are explained in detail in this chapter. The other coating

finishes, which are used on other architectural metals as well, are discussed in detail in Chapter 5, Applied Coatings.

Note that most of the finishes in the following Summary are not applied by the prime producers of aluminum, but by other processors or by the manufacturers of the end use products. The only true mill finishes, in fact, are the "As Fabricated" finishes, though some producers also supply sheet and coil stock with organic and laminated coatings, as well as patterned sheet. All of the other finishes are referred to as process finishes, being applied by others after the metal leaves the mill.

SUMMARY OF TYPICAL ALUMINUM FINISHES

Finish	Aluminum Association Finish Designation (see page 14)	Finish Normally Supplied By			Relative Costs (on flat surfaces)
		Mill	Proces- sor	Fabricator or Finisher	
MECHANICAL					
As Fabricated	M10 Series	X			base
Buffed	M20 Series			X	wide range ¹
Directional Textured	M30 Series			X	wide range
Non-Directional Textured	M40 Series			X	wide range
Patterned	MnX (Specify)	X	X		low to medium ²
CHEMICAL					
Cleaned only	C10 Series		X	X	very low
Etched	C20 Series			X	very low
Brightened	C30 Series			X	very low
Conversion Coatings	C40 Series	X	X	X	very low
Other	CnX (Specify)	X	X		low to medium ²
ANODIC COATINGS					
General	A10 Series		X	X	medium to high
Protective/Decorative	A20 Series		X	X	medium to high
Architectural Class II	A30 Series			X	medium to high
Architectural Class I	A40 Series			X	medium to high
Other	AnX (Specify)				
Electroplated and Other Metal	E Series				
ORGANIC COATINGS					
Resinous (See Chapter 5)	R Series	X	X	X	low to medium
Vitreous (See Chapter 5)	V Series		X	X	high
Laminated (See Chapter 5)	L Series	X	X		medium

The term PROCESSOR, as used here, refers to a "middleman" between the mill and the fabricator, who applies coatings, textures or other finishes to metal in bulk form, generally cut sheet or strip or coil stock. FABRICATOR refers to the producer of stock metal shapes or the manufacturer of the end-use product. He either provides the final finish, or sends the fabricated product to a finisher who does this work. The FINISHER does not usually fabricate products, but provides finishes as specified, to products fabricated by others.

The RELATIVE COSTS indicated are necessarily approximate, for general guidance only. Exact costs vary considerably with quantity, type of product, method of application, quality of work and other influences, and should always be verified.

¹ If these finishes are applied by automatic means in production lines, the cost is generally low, but if applied by hand methods, as is sometimes necessary, it can be relatively high.

² Certain embossed patterns, because of their stiffening effect, permit the use of thinner metal, and this saving can in some cases offset their cost. In other cases patterned finishes involve extra costs.

Mechanical Finishes

Mechanical finishes are those that involve the use of no chemical or electrochemical treatment and no additive but provide a surface texture by mechanical means alone. These textures vary widely in character, ranging from the surface appearance resulting from the various production processes to highly reflective surfaces produced by successive grinding, polishing and buffing operations, with costs also varying considerably, in proportion to the amount of processing required.

“As Fabricated” Finishes

The term “As Fabricated” can refer either to the metal stock or to a fabricated product. As a finish designation for aluminum stock it refers to the surface appearance and texture imparted to the metal by the rolling mill, extrusion press, or casting mold which shapes it. Subsequent fabrication operations on the aluminum, such as forming, sawing, punching, drilling, milling, etc., including scratches, can mar the “as fabricated” finish. Under some conditions the marring can be corrected by simple mechanical deburring and smoothing. For other conditions, the marring results in an unacceptable “as fabricated” mechanical finish, and a subsequent finishing operation will be required and should be specified. The subsequent operations most commonly specified for aluminum are a smooth specular buffed finish or a medium satin directional textured finish. Where welding is required on exposed surfaces, discoloration and surface irregularities will result. Discoloration on etched or anodized surfaces resulting from welding cannot be removed.

“As Fabricated” mechanical finishes, as a class, are the simplest and least expensive obtainable. Such finishes can be quite acceptable for architectural applications and are widely used. Typical of these are specular “as fabricated” cold rolled sheet and nonspecular “as fabricated” extrusions. Highly polished rolls used at the mill for the final pass provide the specular finish on the cold rolled sheet. Carefully machined and well maintained dies for the extrusion press ensure extruded surfaces free of objectionable die marks or striations.

The uncontrolled natural finishes resulting from the different forming processes vary somewhat according to the process. Hot rolled and heat treated products have a comparatively dull surface finish and show a certain amount of darkening or discoloration, while cold rolled surfaces have a

brighter and more metallic color. Extruded products have an intermediate appearance, somewhat resembling that of cold rolled items, and can have noticeable surface striations caused by the extrusion die. Castings have a rougher matte finish, die castings being the smoothest and sand castings the roughest.

The typical variations of the “As Fabricated” finish can be identified as follows:

- a) **Unspecified:** This is the natural finish provided by extrusion, casting, hot rolling or cold rolling with unpolished rolls. On rolled products it can vary from dull to bright, and can have stains or light films of rolling oil.
- b) **Specular as fabricated:** A mirror like cold rolled finish, produced on one or both sides of sheet by final passing through highly polished rolls. Not applicable to extrusions, forgings or castings.
- c) **Nonspecular as fabricated:** This is a designation used to refer to a more uniform finish than that provided under the “Unspecified” classification but lacking the specularity of the “Specular as fabricated” finish.

Buffed Finishes

These finishes are generally produced by successive processes of grinding, polishing and buffing, or by buffing alone, if the “as fabricated” finish is acceptably smooth. They are used where a top quality bright appearance is required, and are frequently specified for entrance doors and their framing or for highlighting extrusions and patterned sheet, as well as for hardware. Because of their high reflectivity they should not be used on wide flat surfaces. The cost of these finishes varies widely with the complexity of the product and the number of steps required to achieve the desired effect.

These are process finishes, applied by the fabricator or finisher, and among the many variations possible, two types are generally considered as standard:

- a) **Smooth specular** (mirrorlike): This is the brightest mechanical finish obtainable and is produced by buffing. In order to achieve this lustrous finish the surface is ground and/or polished in one or more stages prior to buffing. When this is required, the final finishing prior to buffing is done with 320 grit.
- b) **Specular:** This finish is accomplished by buff-

ing only, no preliminary grinding or polishing operations being necessary. The resulting finish can show some evidence of scratches or other surface irregularities.

Directional Textured Finishes

Finishes of this type are used in many applications where a smooth satiny sheen of limited reflectivity is desired. The characteristic soft texture results from tiny, nearly parallel scratches in the metal surface produced by wheel or belt polishing with fine abrasives, by hand rubbing with stainless steel wool, or by brushing with abrasive wheels. Always be sure when using any metal finishing materials to clean the aluminum prior to any anodizing process. In belt polishing, the fineness of the finish is controlled by the size of the grit used, the speed of the belt, the hardness of the block or pad used, the pressure exerted on the block, and the condition of the belt.

These are all process finishes, and generally five standard types are recognized:

- a) **Fine satin**
 - b) **Medium satin**
 - c) **Coarse satin**
- } These finishes are produced by wheel or belt polishing with grits of varying degrees of fineness.
- d) **Hand rubbed:** This is another type of satin finish obtained by rubbing with abrasive cloths or with stainless steel wool of increasing degrees of fineness, finishing with No. 0 or No. 00. Hand rubbing is a comparatively expensive finishing process, and is used only where the nature of the work being finished makes other methods impractical. It is frequently employed, however, to even out and blend in satin finishes produced by other means. Again, when using any metal materials in finishing, be sure to clean before any anodizing process.
 - e) **Brushed:** Several varieties of directional finish with approximately parallel scratch lines can be produced by using power driven stainless steel wire wheel brushes, brush backed sander heads (Vonnegut wheels), abrasive impregnated foamed nylon discs (Scotch-Brite®), or abrasive cloth wheels (PG wheels). Again, when using any metal materials in finishing, be sure to clean before any anodizing process.

Non Directional Textured Finishes

These are matte finishes of varying degrees of roughness, produced by blasting sand, glass beads, or metal shot against the metal under controlled conditions. Their principal use in architectural work is on items produced by casting.

The texture of the surface is determined by the size and type of abrasive used, the amount of air pressure, and the position and movement of the nozzle. The finer the abrasive the smoother the finish. A comparatively rough finish is obtained by using coarse silica sand, while the smoothest finishes are obtained by dust blasting with a very fine abrasive and by “vapor honing” with a slurry of extremely fine abrasive and water.

The architect should recognize that these finishes produced by blasting have restricted applicability. Because the impingement of the abrasive under pressure tends to distort the metal, their use is not recommended on material less than ¼ in. (6 mm) thick. There is usually difficulty, too, in obtaining uniform appearance, especially after anodizing, unless special equipment is used to regulate pressure and nozzle movement.

Since the surface produced by even the finest abrasive is actually rough, readily shows fingerprints, and collects and retains dirt, some type of protective treatment is necessary to retain a clean appearance. Clear lacquers are often used for this purpose, and anodizing provides an excellent protective coating, particularly on castings, where such finishes are most appropriate.

The common variations of the sandblasted finishes obtained by using washed silica sand or aluminum oxide of different degrees of fineness are:

- a) **Extra fine matte**
- b) **Fine matte**
- c) **Medium matte**
- d) **Coarse matte**

Shot blasting is used to provide peened finishes. By using steel shot of different sizes the following standard variations are produced:

- e) **Fine shot blast**
- f) **Medium shot blast**
- g) **Coarse shot blast**

Note: steel shot can become impregnated in aluminum causing a problem of dissimilar metals. This also will cause serious problems during the anodizing process.

Patterned Finishes

Patterned finishes are available in thin sheet, in a wide variety of sculptural designs and textures. These are produced by passing “as fabricated” sheet either between two machined matched design rolls, impressing patterns on both sides of the sheet (embossing), or between a design roll and a smooth roll, “coining” one side of the sheet only.

Some coined and embossed patterns are available from the mill; others are produced only by secondary processors.

Chemical Finishes

There are numerous methods of providing intermediate process finishes on metals by washing or dipping the fabricated product in chemical solutions, and many of these are of a proprietary nature. Such treatments have a variety of specific purposes, but in general they are used

- to merely clean the surface, without otherwise affecting it.
- to provide a clean matte textured surface (by etching),

PRECAUTIONS

Regarding the Use of Mechanical Finishes on Aluminum

An “As Fabricated” finish is the finish on the metal as it is received from the rolling mill, roll former, extrusion press, or casting mold, prior to any further mechanical, chemical, anodic, organic, or vitreous finishing operation. In many architectural applications this finish will be acceptable without further mechanical finishing. However, in some products, fabrication operations subsequent to the original as fabricated finish, such as forming, sawing, punching, drilling, milling, etc., can mar the finish so that it is unsatisfactory for architectural applications.

Clad sheet should not be mechanically finished because of the possibility of penetrating such products. It will be necessary to perform additional mechanical finishing operations, and these should be specified for the cladding.¹

Buffed finishes are not recommended for broad surfaces where visual flatness is desired. The high reflectivity of these surfaces accentuates the waviness or oil canning caused by forming operations or temperature changes and can be objectionable. The use of patterned or etched sheet, with or without formed contours, is advised for such applications.

Bright finishes accent all surface blemishes while satin finishes tend to minimize surface blemishes.

Sandblast finishes should not be specified for thin sheet because distortion usually results.

Chemical etching will usually cause noticeable discoloration at welded joints regardless of mechanical or anodic finishes. Where etching and anodizing are to be used, the product, if possible, should be designed so that welded joints are not exposed. The degree of discoloration will depend on both the parent alloy and the filler alloy used for welding. In the selection of filler alloys ease of welding, strength of joint, color matching, and the effect of subsequent heat treatment are factors which must be considered. Some combinations of parent alloys and filler alloys can provide acceptable color matching but not provide adequate strength, and vice versa. Information on this subject is available from The Aluminum Association, or contact the finisher.

All surface protective coverings such as non-adhesive papers, adhesive papers, and stripable plastic films should be removed after receipt at the site as soon as there is no longer a need for the protection. These coverings can affect the surface finish and become brittle and unpeelable under exposure to sunlight and the elements as well as cause staining on the finished product.

¹To improve the finishing characteristics and increase the corrosion resistance of certain alloys in sheet and plate form, they are sometimes “clad” with other aluminum alloys. The thickness of the cladding on each side is usually 5% or less of the total thickness, hence it can be penetrated by abrasive processes.

- to produce a smooth, bright finish, or
- to chemically convert the surface of the metal, providing a film which is a good substrate for organic coatings.

Many types of chemical treatment are used on aluminum as finishing processes, but few of these are in themselves true finishes. Most of them are intermediate steps in an overall finishing process, requiring at least the subsequent application of some form of protective coating.

Non-etch Cleaning

Various chemical treatments are widely used to thoroughly clean the metal preparatory to the application of other finishes. These have no physical effect upon the surface of the metal, and can not be classified as true finishes. They produce a chemically clean surface which is free of all foreign matter such as oil, grease, fingerprints, solid particles of any kind, tarnish, other chemical reaction products, and even surface absorbed gases. Such preparatory cleaning is essential for the successful application of any type of additive coating.

Two such cleaning methods are commonly used:

- Degreasing:** Vapor degreasing exposes the metal to vapors from chlorinated solvents such as trichlorethane and perchlorethylene, and is performed in special degreasing machines. Solvent or solvent emulsion cleaning, with hydrocarbon solvents, is used to remove oil and grease from the metal surface, and is less expensive than vapor degreasing. To achieve maximum cleanness, degreasing of any type should be followed by chemical cleaning. Check to see if this method is subject to EPA regulations.
- Chemical cleaning:** This method is used when animal fats and oils must be removed. The metal can be sprayed with, or immersed in, any number of proprietary or non proprietary solutions, usually at elevated temperatures, after which it is rinsed with water. Inhibited chemicals are used on aluminum, to prevent etching of the surface. Solutions used on ferrous metals are usually not appropriate because of their etching effect. Most of the commonly used cleaners are special detergent products.

Matte Finishes

Finishes of this type are referred to as etched finishes in the aluminum industry, where chemical etching is a very common finishing treatment. The so-called “frosted” finishes are obtained by this means, and the etching process is often used also to prepare surfaces for anodizing. Where a less durable finish is acceptable, the etching can be followed by simply the application of a protective coating of clear lacquer.

These finishes change the surface texture of the metal from a metallic shine to a satin or dull sheen, and are regulated to give varying degrees of roughness. This controlled surface roughening can be accomplished either by alkali solutions with various additives or by various acid solutions. Where production quantities are involved, the cost of obtaining satin finishes by such means is usually much less expensive than that of producing them mechanically. However, for short runs, or when dealing with assemblies of various metals or large assemblies with only small areas to be finished, mechanical methods may be preferable.

A wide variety of acid and alkaline etches is used, producing various degrees of matte finish. The more common of such standard finishes are:

- Fine matte:** This finish is produced by using a mild alkali solution such as trisodium phosphate.
- Medium matte:** The most common “caustic etch” finish, obtained by treating the surface with sodium hydroxide (caustic soda).
- Coarse matte:** This finish is generally produced by using a solution containing sodium fluoride plus sodium hydroxide.

Bright Finishes

A variety of bright finishes, ranging from “mirror bright” to “diffuse bright,” are produced either by chemical brightening, obtained by immersing the metal in certain acid solutions, or by electrolytic brightening—both methods producing visually similar results.

In electropolishing, minute irregularities in the metal surface are removed by making the article to be brightened the anode in an electrolyte. This process produces surfaces that are free from mechanical stresses and embedded abrasive particles, and also results in a somewhat different appearance than that produced by mechanical buffing.

For aluminum products there are two standard types of bright finish, designated as:

- a) **Highly specular:** This finish is the result of preliminary buffing, followed by electropolishing or chemical brightening, and produces a mirror like surface on certain alloys. It is widely used as a finish for reflectors.
- b) **Diffuse bright:** A finish generally produced by first applying a caustic etch (medium matte) finish, followed by chemical brightening.

Conversion Coatings

Although chemical conversion coatings are generally used on aluminum to prepare the surface for painting, some types can also be used as a final finish.

Since the natural oxide film on aluminum surfaces doesn't always provide a good bond for paints, other organic coatings, and laminates, its chemical nature is often "converted" to improve adhesion and undercoating conversion protection. These "conversion films" or "conversion coatings" are generally applied by use of phosphate or chromate solutions, many of which are proprietary in nature. One of the simplest methods of improving the adhesion of organic coatings is to etch the surface with a phosphoric acid solution, thus providing a good mechanical bond.

The conversion "finishes" commonly used are:

- a) **Acid-chromate fluoride treatments**, also provided by proprietary chemicals and result-

ing in either clear or yellowish surface colors. Finishes of this type are usually governed by ASTM B 449, Specifications for Chromates on Aluminum. The proprietary solutions used include Bonderite 714 and 721, Alodine 1200 series, NR2 and NR3, and Iridite 14 and 14-2.

- b) **Acid-chromate fluoride phosphate treatments**, which generally employ proprietary chemical processes and result in either a clear or typically greenish surface color. Among the more common of these processes are Alodine 407-47 and 401-45, and Bonderite 701, the former producing a light green surface suitable as a final finish.

- c) **Acid-chrome free phosphate free fluoride treatments** usually use proprietary chemical processes and produce a clear or iridescent surface color. Among the proprietary finishes of this type is Alodine 4830/4831

NOTE: Alodine, Bonderite and Iridite are registered trade names of Parker/Amchem and Allied Kelite Division of The Richardson Company, respectively.

Anodic Coatings

Probably the most important, and certainly the most unique, of all of the aluminum finishes is that provided by the anodizing process. In essence, the anodizing process consists of immersing the aluminum to be anodized in an appropriate acid solution, referred to as the electrolyte, and passing a direct electric current between the aluminum and the elec-

PRECAUTIONS

Regarding the Use of Chemical Finishes on Aluminum

Proper pretreatment is absolutely essential to the satisfactory performance of the subsequently applied finishes. For organic coatings it should take place immediately prior to the application. Strict quality control is a necessity throughout the process.

Chemically brightened finishes for large surfaces such as fascias and spandrel panels can cause handling problems and some difficulty in obtaining uniformity under production conditions.

Chemical finishing of assemblies involving different metals or alloys is usually impractical because each of the different metals or alloys is likely to be affected differently.

All surface protective coverings such as non-adhesive papers, adhesive papers, and strippable plastic films should be removed after receipt at the site as soon as there is no longer a need for the protection. These coverings can affect the surface finish and become brittle and unpeelable under exposure to sunlight and the elements.

trolyte, with the aluminum acting as the anode. This results in the controlled formation of a durable oxide film or coating on the surface of the aluminum. In general, such coatings are many times thicker than the naturally formed oxide film and can be transparent, translucent or opaque, depending on the alloys and/or processes used. Anodic coatings do not affect the surface texture of the aluminum, however fine this texture is, but they greatly increase resistance to corrosion and provide increased resistance to abrasion.

Proper surface treatment prior to anodizing is essential. This will require the use of the appropriate chemical cleaning and finishing processes described under **Chemical Finishes**. If soil or grease are present their removal by vapor degreasing or inhibited chemical cleaner is the first requirement. All metal residue from finishing or grinding must also be removed. Chemical etching or brightening are commonly used following the cleaning where the final appearance requires such preanodizing treatments. Etching is the most economical and most extensively used pre finish. Its matte appearance is not only attractive, but it effectively conceals minor surface marring.

Pre anodizing treatments can receive one of the buffed, directional, non directional or patterned finishes described under **Mechanical Finishes**. However, "as fabricated" mill finishes on both sheet and extrusions are of a quality that eliminates the need for a subsequent mechanical finishing operation. Because of this, most architectural products today are simply etched and anodized.

Several different anodizing processes are presently used for architectural aluminum products. The principal differences in these processes are the solutions used for the electrolytes, the voltages and current densities required, and the temperature at which the electrolyte is maintained. Depending on which process is used, and the length of treatment time, the anodic coating will vary somewhat in thickness, hardness and porosity. Because of this there are some differences in the protective capabilities of the different coatings.

Clear anodic coatings are produced by the **sulphuric acid process** which was the first commercially used process for anodizing architectural aluminum. It imparts an excellent, comparatively thick, transparent, durable, protective coating to the aluminum surface, and it is economical.

Color anodic coatings are obtained by impregnating the coating with organic dyes or pigments, by using alloys and processes that produce integral color, or by electrolytically depositing pigments in the anodic film. The clear anodic coatings produced by the sulfuric acid process are suitable for accepting a wide variety of organic dyed colors considered sufficiently resistant to ultraviolet degradation for exterior use.

Integral color anodic coatings in the bronze-grayblack range are produced by both the basic sulfuric acid process and by proprietary mixed acid processes. These colors are durable, have good resistance to ultraviolet, and are widely used for exterior applications of architectural aluminum products. One such process also goes by the title Duranodic Process.

In the basic sulfuric acid anodizing process, integral colors can be obtained with certain controlled alloys and by employing lower temperatures and higher current densities than those used in the conventional process. Coatings so produced are referred to as integral color hardcoats. With proprietary mixed acid electrolyte processes, controlled alloys and higher current densities are also used, and temperatures are closely controlled as are the concentrations of the mixed acids. With mixed acids, integral colors can be obtained without the relatively low temperatures required for the sulfuric acid process, hence they are more economical to produce. The color and the shade of the oxide coatings produced by these processes are determined by the composition and temper of the alloys used, by the concentration of acids in the electrolyte, and by anodizing conditions such as time, temperature, and current density.

Brite Dip Anodizing is used primarily in the bathroom fixture industry. This 'brite' finish is accomplished by a mixture of Nitric acid and Phosphoric acid. The vapors from this process are environmentally hazardous and not available everywhere. There is a chemical brightening process, basically electropolishing, that is starting to replace the older more hazardous process when this brite appearance is requested.

Electrolytically deposited anodic coatings are produced by proprietary processes used in conjunction with sulfuric acid anodizing and provide colors in the light bronze to black range, similar to those produced by integral color processes and equally appropriate for exterior use.

The colors, as the name of the process implies, are obtained through the electrolytic deposition of colorfast, stable, metallic pigments in the base of the pores of the anodic coating by submersion in a metal salt bath, such as cobalt or tin, under low power.

For architectural applications the thickness and weight of the coating are of prime importance. Coatings specified for exterior applications exposed to atmospheric pollutants, or not having regular maintenance, should have at least 0.7 mil thickness and a minimum coating weight of 27 mg. per square inch. For resistance to extreme exposure conditions such as sea water or abrasive actions, integral color hardcoats up to 3.0 mils thick have been used.

In all of the architectural anodizing processes the subsequent sealing of the pores in the oxide coating is a prime essential. The sealing of the pores is done to make the coating nonabsorbent and to provide maximum resistance to staining and corrosion. Clear, integral color and electrolytically deposited color coatings are usually sealed in deionized boiling water or metal salt sealants.

Surfactants and wetting agents can be used, but they should be controlled so as not to cause poor adhesion of any organic overcoating.

Classification of Anodic Coatings

For purposes of identification, the various anodic finishes are classified by the Aluminum Association under four general types: General Anodic Coatings, Protective and Decorative Coatings, Architectural Class II Coatings and Architectural Class I Coatings. Each of these classifications has several subdivisions, as shown in Table 1-5, page 1-21.

The first two classifications apply to general industrial work, not to architectural products. Only the last two, as their names indicate, are of architectural interest and will be described here.

Architectural Class I Coatings

These are coatings 0.7 mil or more in thickness and weighing not less than 27 mg. per sq. in., or a density not less than 38 g per sq in., and include the hardest and most durable anodic coatings available. They are appropriate for interior architectural items subject to normal wear, and for exterior items that receive a minimal amount of cleaning and maintenance. It is possible to produce hard coat Class I finishes in thicknesses ranging from 1 to 3 mils.

Coatings in this range have been used successfully in such applications as railings on piers which are subject to severe salt water exposure. However, production of these thick hard coat finishes requires special anodizing facilities of which there are only a limited number in this country. Availability should be checked. Please note that the heavier Class I coating will actually enhance surface imperfections and blemishes rather than hiding them.

Architectural Class II Coatings

Thickness of these coatings ranges from 0.4 to 0.7 mils, with corresponding weights of from 15.5 to 27 mg per sq in., or a density ranging from 22 to 38 g per sq in.; the lower figures being the minimums recommended for architectural uses. Coatings of this class are appropriate for interior items not subject to excessive wear or abrasion, and for exterior items such as storefronts and entrances, which are regularly cleaned and maintained.

Quality Control Tests

After anodizing is completed, tests are performed on representative samples taken at random from the rack loads to determine that the coating meets the specified thickness and weight and is properly sealed. The following *ASTM Test Methods* for checking thickness and weight are universally accepted and recommended, and should be specified:

- *ASTM B 244, Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy Current Instruments.* This non destructive method determines coating thickness by the lift off effect of a probe coil that contacts the coating and generates eddy currents in the aluminum substrate.

- *ASTM B 137, Test Method for Measurement of Weight of Coating Mass per Unit Area on Anodically Coated Aluminum.* This test involves weighing a small sample of known surface area on an analytical balance, dissolving the coating in a solution that does not attack the aluminum, then reweighing the specimen and comparing weights.

Properly sealed anodic coatings are proof against absorption of coloring materials or staining. To check for proper sealing the following stain test can be used:

- *ASTM B 136, Test Method for Measurement of Stain Resistance of Anodic Coatings on Aluminum.*

PRECAUTIONS

Regarding the Use of Anodic Coatings on Aluminum

Anodic coating can be restored only by removing the coated item and refinishing it in the shop, at the cost of considerable time and expense. Items subject to heavy wear or abrasion should therefore either receive a sufficiently heavy coating to insure that it will not be worn through, or should be given some other type of finish that can be more easily restored,

Flash welding can be successfully done on frontal areas to be anodized, providing the “flash” is mechanically removed, but arc welding of assemblies to be anodized should be done only in concealed areas, because objectionable discoloring can result. If required, it should be undertaken only with the advice of a competent and experienced fabricator. The selection of filler rod for welding is also very important. If the wrong material is used, any exposed weld joint can turn black in the anodizing process. The most common filler rod if the aluminum is to be anodized is 5356 or 5856 Rod. Again, hidden welds if possible or minimal welds are preferred because even with these filler materials, a noticeably different shade in the weld area will be seen after anodizing.

Joints between large anodized panels should be interrupted with divider strips, shadow lines, or changes in plane or texture, rather than being treated as simple butt joints, to minimize variations in shade.

Assemblies which are to be anodized must have drainage holes provided, so that acid trapped in hollow areas can drain out and be properly flushed. Acid trapped in joints must also be thoroughly washed out. Otherwise, it will drain out after installation, causing objectionable stains.

When thick sheet is used for components which are to be anodized, and no grinding, polishing or buffing is required, a specialty sheet product should be specified, to minimize “structural streaking.” Specialty sheet is not generally recommended, however, if mechanical finishing is intended, but the finish in such cases should be sufficiently textured to conceal the “structural streaking.” If a textured finish is not acceptable, thicker specialty sheet can be used, provided extreme care is exercised during both the fabricating and finishing processes.

Composite structures consisting of wrought, cast, and welded aluminum will exhibit extreme ap-

pearance differences after anodizing due to their differing alloy composition and metallurgical structure. Aluminum that has been cold worked extensively, such as in tapered aluminum flagpoles and lighting support poles, can exhibit apparent color variation within a single alloy after anodizing. This color variation due to anodizing cold worked aluminum cannot be controlled. Anodizing should not be specified for composite or extensively cold worked structures when appearance differences are unacceptable.

In specifying color anodizing it must be recognized that each alloy produces its own characteristic shade, and specific colors can be provided only by certain alloys. The selection of alloys should be carefully specified and controlled, and not mixed indiscriminately.

For example, the ‘Duranodic’ process mentioned above requires either of four series of alloys to get the proper color: 1100, 5000, 6000, or 7000. However, mixing them together in a structure, and in some cases within the same alloy (i.e. 6061 & 6063), does not provide the same coloring on the entire weldment. All will shade differently when anodized together.

Specifications should include the requirement of color samples showing the color range to be expected in production of any specific color and shade.

With the exception of lead and titanium, other metals should not be included in assemblies to be anodized, as the anodizing process will dissolve them.

All surface protective coverings such as adhesive paper and strippable plastic films should be removed as soon as possible after installation because they can become brittle and unpeelable under exposure to sunlight and weather, and under these conditions they can cause staining.

For maintenance of anodic finishes ordinary wax cleaners, soap or mild detergents and water are generally satisfactory. DO NOT USE alkaline or acid materials. Some anodizers offer touch-up materials, in either spray or liquid form, to their customers.

Refer to AAMA 609/610-02, “Cleaning and Maintenance Guide for Architecturally Finished Aluminum.”

Quality of the seal can also be checked by the following ASTM and ISO (International Standards Organization) tests:

- *ASTM B 680, Test Method for Seal Quality of Anodic Coatings on Aluminum by Acid Dissolution.*
- *ISO 3210, Assessment of Sealing Quality by Measurement of the Loss of Mass after Immersion in Phosphoric Chromic Acid Solution.*
- *ASTM B 457, Test Method for Measurement of Impedance of Anodic Coatings on Aluminum.*
- *ISO 2931, Assessment of Quality of Sealed Anodic Oxide Coatings by Measurement of Admittance or Impedance.*

Recommendations of the proprietary process anodizers should be followed with regard to seal tests.

Guide Specifications and Inspection Methods

Four publications of the American Architectural Manufacturers Association (AAMA) are recommended as references for those who desire more detailed information or who require guidance on specifying and inspecting anodized finishes for architectural aluminum products. These publications are listed below:

- *AAMA 611-98, Voluntary Specification for Anodized Architectural Aluminum.*
- *AAMA 2603-02, Voluntary Specification, Performance Requirements and Test Procedures for Pigmented Organic Coatings on Aluminum Extrusions and Panels.*
- *AAMA 2604-02, Voluntary Specification, Performance Requirements and Test Procedures for High Performance Organic Coatings on Aluminum Extrusions and Panels.*
- *AAMA 2605-02, Voluntary Specification, Performance Requirements and Test Procedures for Superior Performing Organic Coatings on Aluminum Extrusions and Panels.*

Care and Maintenance of Anodized Aluminum

(The material appearing in this section has been excerpted from AAMA "Care and Handling of Architectural Aluminum from Shop to Site," CW-10-97. See also, Chapter 5, Applied Coatings.)

General Considerations

Building owners and managers, along with the architects who have designed their buildings, have

always been concerned about the appearance of the exterior wall. The attractiveness of the wall design and the continued excellent appearance of a properly located building brings in and keeps satisfied tenants. The architect who has specified anodized aluminum wall and window components has done so first because of the beauty which can be achieved with such anodized finishes and second because of the long life, durability, and low maintenance that these finishes provide. It then becomes the responsibility of the building owner or manager to see that the original beauty of the building exterior is maintained in order to preserve the desirability and profitability of the property.

The American Architectural Manufacturers Association, recognizing the need for the aluminum industry to provide information on the care and maintenance of exterior wall finishes, released a publication titled "*Cleaning and Maintenance Guide for Architecturally Finished Aluminum, AAMA 609/610-02.*" This specification outlines methods, equipment, and materials to clean anodized aluminum after construction and for subsequent, periodic maintenance. The methods outlined are applicable to architectural products fabricated from both rolled and extruded shapes, including window and door frames, store fronts, and entrances, curtain walls, mullions, hand rails, flag poles, and hardware. The information provided in the specification is useful to building owners, managers, architects, contractors, and others in the building industry who are interested in the proper care and maintenance of anodized aluminum.

As with any finished building material, aluminum requires reasonable care prior to and during installation and periodic cleaning and maintenance after installation. Although anodized aluminum is exceptionally resistant to corrosion, discoloration and wear, its natural beauty can be marred by harsh chemicals, abuse, or neglect. Such conditions usually affect only the surface finish but do not reduce the service life of the aluminum. All exterior surfaces collect varying amounts of soil and dirt, depending on geographic area, environmental conditions, finish and location on the building. These factors and the owner's attitude regarding surface appearance determine the type and frequency of cleaning required. The aluminum cleaning schedule should be integrated with other cleaning schedules for efficiency and economy. For example, both the glass and the aluminum

curtain wall can be cleaned at the same time.

Cleaning may be required more often in one geographic area than another when appearance is of prime importance. More frequent cleaning will be required in heavy industrialized areas than in rural areas. Seasonal rainfall can affect washing frequency by removing water soluble deposits and less adherent soil. In foggy coastal regions, frequent cycles of condensation and drying can create a heavy buildup of atmospheric salts and dirt which can adhere tenaciously. In climates where the rainfall is low, the opportunity for atmospheric washing of the surface is minimal. Los Angeles, for example, with its unique combination of limited rainfall, temperature fluctuation, smog and condensation, requires that aluminum be cleaned more frequently than in other metropolitan areas with more frequent rainfall.

In both wet and dry climates, recessed and sheltered areas usually become more heavily soiled because of the lack of rain washing. More frequent and longer periods of condensation also occur in protected areas, increasing the adhesion of the soil. This is particularly true of soffit areas on overhangs, bottoms of fascia panels, sheltered column covers, and the like. Periodic maintenance inhibits long term accumulation of soil which, under certain conditions, can accelerate weathering of the finish.

Cleaning Procedures

Cleaning procedures for aluminum should be initiated as soon as practical after completion of installation to remove construction soils and accumulated environmental soils and discolorations.

Cleaning work should start at the top of the building and proceed to the ground level in a continuous drop. Using a forceful water spray, an area the width of the stage or scaffolding should be rinsed as cleaning proceeds from the top down.

Because surface soils can be light or heavy, several progressively stronger cleaning procedures can be employed depending on the severity and tenacity of the soil. Only trial and error testing can determine which will be most effective. The simplest procedure to remove the soil is the one which should be used.

For light soils, the simplest procedure is to flush the surface with water using moderate pressure. If soil is still present after air drying the surface, scrubbing with a brush or sponge and concurrent spraying

with water should be tried. If soils still adhere, then a mild detergent cleaner should be used with brushing or sponging. Washing should be done with uniform pressure, first horizontally then vertically. Following the washing, the surfaces must be thoroughly rinsed by spraying with clean water.

If it is necessary to remove oil, wax, polish, or other similar materials, methyl-ethyl-ketone (MEK) or an equivalent solvent is recommended for clean up. Extreme care must be exercised when solvents of this type are used since they can damage organic sealants, gaskets and finishes. These solvents should never be used on anodic finishes protected by clear organic coatings unless the organic coating has deteriorated and should be removed.

Removing heavy surface soils can require the use of an abrasive cleaning pad. In this procedure the pad is thoroughly soaked with clean water or a mild detergent cleaner and the metal surface is hand scrubbed with uniform pressure. Scrubbing action should be in the direction of the metal grain. Scrubbing with a nylon cleaning pad impregnated with a surface protectant material is also recommended for removing stubborn soils and stains. After scrubbing, the surface should be rinsed thoroughly with clean water to remove all residue. In some circumstances it is necessary to wipe the surface with a solvent. The surface is then permitted to air dry or is wiped dry with a chamois, squeegee or lint free cloth.

Power cleaning tools can be used to remove unusually heavy soils from large areas including panels and column covers. When using such tools, the surface must be continually flushed with clean water or a mild detergent cleaning solution to provide lubrication and a medium for carrying away the dirt. After an area has been machine scrubbed, it must be rinsed with clean water and thoroughly scrubbed with a fairly stiff bristle brush. The surface is then either air dried or wiped dry.

Inspection

It is suggested that the building owner or manager provide an engineer or other qualified representative to inspect the cleaning work. Care must be taken to see that metal seams, crevices, sills, and other areas that can trap water, cleaner, or dirt are carefully cleaned and dried. A final inspection to ensure that no discoloration or stains remain on the surface is recommended.

Cleaning Precautions

Certain precautions must be taken when cleaning anodized aluminum surfaces. Aluminum finishes must first be identified to select the appropriate cleaning method. Aggressive alkaline or acid cleaners must never be used. Cleaning hot, sun heated surfaces should be avoided since possible chemical reactions will be highly accelerated and cleaning non uniformity could occur. Strong organic solvents, while not affecting anodized aluminum, can extract stain producing chemicals from sealants and can affect the function of the sealants. Strong cleaners should not be used on window glass and other components where it is possible for the cleaner to come in contact with the aluminum. Excessive abrasive rubbing should not be used since it could damage the finish.

Field Protection and Maintenance

Field protection and maintenance of cleaned surfaces is of particular interest. A wipe-on surface protectant is now available which is estimated to provide protection for 12 to 24 months in the harshest environments. This protectant is applied to a thoroughly cleaned and dried anodized surface with a lint free cloth or felt pad. The benefits of such an application are twofold; first, it protects the finish, and second, it makes subsequent maintenance easier. Subsequent maintenance can be reduced to simply flushing the surface with water, permitting it to dry and wiping on a surface protectant every few years. In applying this protectant it is very important that the manufacturer's recommendations be carefully followed.

Equipment and Products

Equipment and products needed for cleaning and maintaining anodized aluminum finishes are listed in Section 7 of AAMA 609/610-02. These include mild soaps, detergents, non etching cleaners, abrasive cleaning pads and cleaning machines. AAMA, however, has not evaluated these materials nor does its listing constitute an endorsement. This list is included only as an aid to potential users in identifying the materials.

Many waxes are available for application to anodized finishes, but they are best used on interior items such as hand rails, doors, and decorative metals. It is generally not practical to use these materials on high rise portions of a building.

Care and Maintenance of Painted Aluminum

(The material appearing in this section has been excerpted from AAMA CW-10-97, Care and Handling of Architectural Aluminum from Shop to Site.)

General Considerations

Care and maintenance guidelines for anodized aluminum also apply to painted aluminum. The architect depends on the finish to provide the beauty in the building he has designed. The building owner and manager want to preserve this beauty thereby preserving the desirability and profitability of the property.

As in the case of anodized aluminum, the American Architectural Manufacturers Association released a publication *Cleaning and Maintenance Guide for Architecturally Finishes Aluminum*, AAMA 609/610-02. This guide outlines methods, equipment, and materials applicable for cleaning architecturally finished aluminum after construction and for subsequent periodic maintenance.

Organic aluminum coatings do not normally show an appreciable amount of dirt accumulation. In many atmospheres, dirt and soil would not be detrimental to the coating, but cleaning and surface care is desirable for the sake of appearance. In areas where heavy industrial deposits have dulled the surface, where materials from construction processes have soiled the surface; or where cleaner has run down from other surfaces, surface cleaning is desirable.

Climatic conditions affect the cleanliness of organic coatings in the same way they affect anodized coatings. In some areas rainfall can be sufficient to keep exterior surfaces looking clean and bright. In areas of low rainfall or in heavily industrialized areas, periodic cleaning will be necessary. This is also true of foggy coastal regions with frequent cycles of condensation and drying which can cause a build up of atmospheric salts and dirt. In any climate, sheltered areas under overhangs can become soiled from lack of rain washing. Cleaning painted aluminum components in the exterior wall may be scheduled along with cleaning the glass.

If automatic wall cleaning equipment is to be used on a building, a test should be made early in the equipment design to ensure that the cleaning solutions and brushes, as well as the frequency of cleaning, will have no detrimental effect on the coating.

Cleaning Procedures

Painted surfaces should be cleaned as soon as possible after installation to remove construction soils and accumulated environmental soils. Ideally, a forceful water rinse from the top down should be employed before applying any cleaner. Some type of surface agitation helps. A low volume of water at moderate pressure is better than a high volume at low pressure. Rubbing the surface with soft brushes, sponges or cloth during the rinsing also helps.

If a simple water rinse with brushing, sponging, or rubbing with a cloth is not sufficient to remove the soil, a mild detergent or mild soap will be necessary.

Washing with a mild detergent or mild soap should be done by brushing or sponging with a uniform pressure, first horizontally, then vertically. Following the washing, the surfaces must be thoroughly rinsed with clean water. If the cleaner has been permitted to dry, sponge the surfaces while rinsing, if necessary. Rinsed surfaces are permitted to air dry or wiped dry with a chamois, squeegee or lint free cloth.

Cleaner run down should be minimized and those areas subject to run down should be rinsed immediately, and as long as necessary, to lessen the probability of streaking.

Cleaning chemicals must not be allowed to collect on surfaces, to “puddle” on horizontal surfaces or to collect in joints and crevices. These surfaces, joints and crevices should be thoroughly flushed with water and dried.

Mild detergents and soaps, which are safe for bare hands, should be safe for coated aluminum. Stronger detergents, such as some dishwasher detergents, should be carefully spot tested. Some of the latter would necessitate using rubber gloves and long handled brushes. Some mild cleaning solutions are available for automatic building washing machines.

Mild solvents such as mineral spirits can be used to remove grease, sealant or caulking compounds. Stronger solvents or solvents containing cleaners can soften paints. To prevent damage to the finish, the coating manufacturer should be consulted and these types of solvent or emulsion cleaners should first be spot tested. Care should be taken to assure that no surface marring takes place in this manner since it could give an undesirable appearance at certain viewing angles. Cleaners of this type are usually

applied and removed with a clean cloth. Remaining residue should be washed with mild soap and rinsed with water. Use solvent cleaners sparingly.

Since solvents can extract materials from sealants which could stain the painted surface or could prove harmful to sealants, their possible effects must be considered. Test a small area first.

If cleaning heavy tenacious surface soil or stubborn stains has been postponed, a more aggressive cleaner and technique is required. Cleaner and technique should be matched to the soil and the painted finish. Some local manual cleaning may be needed at this point. Always follow the recommendations of the cleaner manufacturer as to proper cleaner and concentration. Test clean a small area first. Cleaners should not be used indiscriminately. Do not use excessive, abrasive rubbing since it can alter surface texture or impart a “shine” to the surface.

Dried concrete spillage on the painted surface can be quite stubborn to remove. Special cleaners and/or vigorous rubbing with non abrasive brushes or plastic scrapers may be necessary.

Diluted solutions of Muriatic Acid (under 10%) can be effective in removing dried concrete stains, and effective proprietary cleaners for concrete and mortar staining are available. However, a test area should be tried first, and proper handling precautions must be exercised for safety reasons.

Mixing cleaners **can be very dangerous**, as well as ineffective. For example, mixing chlorine containing materials such as bleaches, with other cleaning compounds containing ammonia, can produce poison gas.

Always rinse the surface after removing heavy surface soil.

Summary of Cleaning Tips

- Overcleaning or excessive rubbing can do more harm than good.
- Strong solvents (MEK for example) or strong cleaner concentrations can cause damage to painted surfaces.
- Avoid abrasive cleaners. Do not use household cleaners that contain abrasives on painted surfaces.
- Abrasive materials such as steel wool, abrasive brushes, etc., can wear and harm finishes.
- Avoid drips and splashes. Remove run downs as quickly as possible.

- Avoid temperature extremes. Heat accelerates chemical reactions and can evaporate water from solution. Extremely low temperature can give poor cleaning results. Cleaning under adverse conditions can result in streaking or staining. Ideally, cleaning should be done in shade at moderate temperature.
- Do not substitute a heavy duty cleaner for a frequently used, mild cleaner.
- Do not scour painted surfaces.
- Never use paint removers, aggressive alkaline, acid or abrasive cleaners. Do not use trisodium phosphate or highly alkaline or highly acid cleaners. Always do a test surface.
- Follow manufacturers recommendations for mixing and diluting cleaners.
- Never mix cleaners.
- To prevent marring, make sure cleaning sponges, cloth, etc., are grit free.
- “An ounce of prevention is worth a pound of cure.”
- In addition to the foregoing, consideration must be given to the effects run down can have on shrubbery, personnel, equipment and other

items located below. Such considerations can affect the timing in the cleaning schedule.

Inspection

It is suggested that the building owner or manager provide a qualified inspector to see that the cleaning operations are carried out in accordance with the recommended procedures.

Standard Finish Designations (as established by the Aluminum Association)

For many years, each of the prime producers of aluminum had his own system for identifying the many different finishes available. This resulted in a bewildering assortment of unrelated finish symbols, confusing to both architects and fabricators. Recognizing the necessity of correcting this situation, the Aluminum Association, in 1959, formed a committee representing all of the major producers, to study the problem and formulate an industry wide designation system acceptable to all.

The result was the Aluminum Association Finishes Designation System, adopted by the Association in 1963 and first published in 1964. Subsequent developments in anodizing processes,

Table 1-1: Finishes for Aluminum Hardware

Listed in this table are the Builders Hardware Manufacturers Association (BHMA) designations for finishes most commonly in use today on aluminum hardware. Since U.S. Finish Designations occasionally appear in specifications, the nearest U.S. equivalents of the BHMA code numbers are shown on the list. For a complete listing and descriptions of hardware finishes refer to *ANSI/BHMA A156.18, American National Standard for Materials and Finishes*.

Code No.	Description	Nearest US Equivalent
627	Satin aluminum, clear coated	US27
628	Satin aluminum, clear anodized	US28
666	Bright brass plated, clear coated	US3
667	Satin brass plated, clear coated	US4
668	Satin bronze plated, clear coated	US10
669	Bright nickel plated	US14
670	Satin nickel plated	US15
671	Flat black coated	US19
672	Bright chromium plated over nickel	US26
673	Aluminum clear coated	USP
688	Satin aluminum, gold anodized	US4

minor modifications, and several new designations have resulted in the current (revised) Designation System.

The Aluminum Association's Finish Designation System, as explained in the following discussion, is designed to cover all commonly used finishes, and provides also for accommodating new finishes as they are developed. The National Association of Architectural Metal Manufacturers endorses this system and recommends its consistent use not only by all of its member companies but by all those who are concerned with identifying and specifying aluminum finishes,

In this system, seven categories—the mechanical finishes, the chemical finishes, and five types of coatings—are designated by different letters as follows:

Mechanical Finishes	M
Chemical Finishes	C
(including conversion coatings)	
Anodic Coatings	A
Resinous and Other Organic Coatings....	R
Electroplated and Metallic Coatings	E
Vitreous Coatings	V
Laminated Coatings	L

Each of these categories in turn includes a variety of specific finishes bearing an identifying two digit number. The designation for any finish, then, consists of one of these seven letters followed by two digits. In the case of Protective and Decorative Anodic Coatings (Table 1-5) three digit numerals are used to further define them by minimum coating thickness and weight. To date, however, numbers have been assigned to only those finishes classified as Mechanical Finishes (Table 1-3), Chemical Finishes (Table 1-4) and Anodic Coatings (Table 1-5).

The method tentatively recommended for identifying other types of coating finish is explained in Table 1-2, which summarizes the system in its present form. It will be seen that designations have not yet been determined for many of the specific types of applied coatings. This matter is still under study, however, and it is anticipated that the sys-

tem will be extended to include at least the more common of these finishes.

The descriptions of finishes given under the heading "Examples of Methods of Finishing" in Tables 1-3, 1-4, and 1-5 are intended only as illustrations of appropriate methods and not as specifications. Alternatives to these methods of obtaining the finish are acceptable, provided that an equivalent finish is produced. There are many variations and limitations of both equipment and procedures in the finishing industry which require modifications of such suggested methods.

Explanation of the Use of the System

Where only a simple finish is called for, a single designation is used alone (e.g. M33), but more frequently two or more designations will be combined to form a composite designation identifying a sequence of operations leading to a final finish (e.g. C22A31).

When designations for chemical or applied finishes are used alone, it is to be understood that other processing steps normally used as preparation for the specified finish can be used at the option of the finisher. When a finish requires two or more treatments of the same class, the class letter should be repeated, followed in each case by the appropriate two digit numeral.

The use of the letter 'x' in all categories of the designation system (e.g. M1x, C2x, etc.) requires additional explanation. This symbol indicates that the Aluminum Association has not yet assigned any specific designations in the classification so designated; any finishes in these categories presently have no recognized numerical designation and must therefore be described in words.

The 'x' symbol is to be used by the specifier; he should not arbitrarily substitute a digit of his own selection in place of the "x."

The procedure to be followed where such finishes are concerned is illustrated in Examples 4 and 5 on page 1-17.

The examples on the following page illustrate the use of the system. Note that each designation is preceded by the letters AA to identify it as an Aluminum Association designation.

Hardware Finishes

Architectural hardware finishes are designated by code numbers established by the Builders Hardware Manufacturers Association (BHMA). The nearest US equivalents of BHMA numbers are listed in its standard *ANSI/BHMA A156.18-2000*. Samples of selected finishes are available from its New York office. The equivalent aluminum finishes are listed in Table 1-1.

Example 1 – Architectural Building Panel

To specify a matte anodized finish such as that produced by first etching the aluminum and then applying a durable clear anodic coating, the architect would use the designation

AA – C22A41, which represents:

C22 – Chemical Finish, Etched, Medium Matte (Table 4)

A42 – Anodic Coating, Architectural Class 1, clear coating 0.7 mil or thicker (Table 5)

Example 2 – Architectural Extrusion with Integral Color

If an architect wishes to specify an anodized finish with a non specular surface and an integral color, he uses the designation

AA – M12C22A42, of color to match approved sample.

These symbols represent:

M12 – Mechanical Finish, Non specular as fabricated (Table 3)

C22 – Chemical Finish, Medium Matte (Table 4)

A42 – Anodic Coating, Architectural Class 1, Integrally colored coating 0.7 mil or thicker (Table 5)

Example 3 – Extruded Assembly, Welded, with Integral Color

Because of the necessity of dressing down and blending the welded areas, a directional textured, rather than bright finish is usually specified in this case, though for some products concealed welding can be successfully used to join prefinished parts. The designation (for a directional finish) should be

AA – M32A42, of color to match approved sample. This calls for:

M32 – Mechanical Finish, Directional Textured, Medium Satin (Table 3)

A42 – As in Example 2 above

Example 4 – Etched Finish with Clear Lacquer Protection

Since clear lacquer is a type of organic coating and, as such, has no specific finish designation, the type to be used must be specified.

This finish, then, would be designated approximately as follows:

AA – C22R1x, using “ABC” Company’s clear methacrylate lacquer No. _____,
applied in two coats with interim drying, to a total thickness of 0.6 mils.
(C22 designates a medium matte etch).

Example 5 – Patterned Sheet with Organic Coating

In this case, both the pattern and the coating must be specified, and the designation would be

AA – M1xC41R1x, using “One” Company’s pattern No. _____ and
“Another” Company’s (brand) coating, _____
_____color, applied... (state requirements)....

(C41 designates acid chromate fluoride pretreatment)

TABLE 1-2 - SUMMARY OF STANDARD DESIGNATIONS FOR ALUMINUM FINISHES

All designations are to be preceded by the letters AA, to identify them as Aluminum Association designations.
Finishes printed in **boldface type** are those most frequently used for architectural work.

MECHANICAL FINISHES (M)			
As Fabricated	Buffed	Directional Textured	Non-Directional Textured
M10—Unspecified	M20—Unspecified	M30—Unspecified	M40—Unspecified
M11—Specular as fabricated	M21—Smooth specular	M31—Fine satin	M41—Extra fine matte
M12—Non-specular as fabricated	M22—Specular	M32—Medium satin	M42—Fine matte
M1x—Other	M2x—Other	M33—Coarse satin	M43—Medium matte
		M34—Hand rubbed	M44—Coarse matte
		M35—Brushed	M45—Fine shot blast
		M3x—Other	M46—Medium shot blast
			M47—Coarse shot blast
			M4x—Other
CHEMICAL FINISHES (C)			
Non-Etched Cleaned	Etched	Brightened	Chemical Conversion Coatings
C10—Unspecified	C20—Unspecified	C30—Unspecified	C40—Unspecified
C11—Degreased	C21—Fine matte	C31—Highly specular	C41—Acid chromate-fluoride
C12—Inhibited	C22—Medium matte	C32—Diffuse bright	C42—Acid chromate
chemical cleaned	C23—Coarse matte	C33—Highly specular	fluoride-phosphate
C1x—Other	C24—Fine matte	C3x—Other	C43—Alkaline chromate
	C25—Adhesion pretreatment		C44—Non-chromate
	C26—Desmut		C45—Non-rinsed chromate
	C27—Desmut		C46—Non-rinsed non-chromate
	C28—Etched designs		C4x—Other
	C2x—Other		
ANODIC COATINGS (A)			
General	Protective and Decorative	Architectural Class II	Architectural Class I
A10—Unspecified	A21*—Clear (natural)	A31—Clear (natural)	A41—Clear (natural)
A12—Chromic acid anodic	A22*—Integral color	A32—Integral color	A42—Integral color
A13—Hard, wear and abrasion resistant coatings	A23*—Impregnated color	A33—Impregnated color	A43—Impregnated color
A14—Nonchromate adhesion pretreatment	A24—Electrolytically deposited color	A34—Electrolytically deposited color	A44—Electrolytically deposited color
A1x—Other	A2x—Other	A3x—Other	A4x—Other

*Third digit (1, 2 or 3) added to designate min. thickness in 1/10 mils. See TABLE 1-5.

ELECTROPLATED (E)

E10—Unspecified

E1x—Specified

ORGANIC COATINGS (R), VITREOUS COATINGS (V), and LAMINATED COATINGS (L)

The following designations can be used until more complete systems are developed.

Resinous and Organic

R10—Unspecified

R1x—To be specified

Vitreous – Porcelain and Ceramic Types

V10—Unspecified

V1X—To be specified

Laminated

L10—Unspecified

L1x—To be specified

TABLE 1-3 - STANDARD DESIGNATIONS FOR MECHANICAL FINISHES

All designations are to be preceded by the letters AA, to identify them as Aluminum Association designations.

Type of Finish	Designation	Description	Examples of Method of Finishing
AS FABRICATED	M 10	Unspecified	
	M 11	Specular as fabricated	
	M 12	Non-specular as fabricated	
	M 1x	Other	To be specified.
BUFFED	M20	Unspecified	Optional with finisher.
	M21	Smooth specular	Polishing with grits coarser than 320 and finishing with 320 grit, using peripheral wheel speed of 6,000 fpm (30 m/s). Then buffing with tripoli based buffing compound, using peripheral wheel speed of 7,000 (36 m/s) to 8,000 fpm (41 m/s).
	M22	Specular	Buffing with tripoli compound, using peripheral wheel speed 7,000 (36 m/s) to 8,000 fpm (41 m/s).
	M2x	Other	To be specified.
DIRECTIONAL TEXTURED	M30	Unspecified	Optional with finisher.
	M31	Fine satin	Wheel or belt polishing with aluminum oxide grit of 320 to 400 size, using peripheral wheel speed of 6,000 fpm (30 m/s).
	M32	Medium satin	Wheel or belt polishing with aluminum oxide grit of 180 to 220 size, using peripheral wheel speed of 6,000 fpm (30 m/s).
	M33	Coarse satin	Wheel or belt polishing with aluminum oxide grit of 80 to 100 size; peripheral wheel speed of 6,000 fpm (30 m/s).
	M34	Hand rubbed	Hand rubbing with stainless steel wool lubricated with neutral soap solution. Final rubbing with No. 00 wool.
	M35	Brushed	Brushing with rotary stainless steel wire brush, wire diameter 0.0095 in. (0.24 mm); peripheral wheel speed 6,000 fpm (30 m/s) or various proprietary satin finishing wheels or satin finishing compounds with buffs.
	M3x	Other	To be specified.
NON-DIRECTIONAL TEXTURED	M40	Unspecified	Optional with finisher.
	M41	Extra fine matte	Air blasting with 200-mesh washed silica sand or aluminum oxide, using 45 psi (310kPa) pressure with gun held 8-12 inches (203-305 mm) from work at 90° angle.
	M42	Fine matte	Air blasting with 100 to 200-mesh silica sand or aluminum oxide. Air pressure 30 to 90 psi (207 to 621 kPa), depending on metal thickness; gun held 12 in. (305 mm) from work at angle of 60° to 90°.
	M43	Medium matte	Air blasting with 40 to 80-mesh silica sand or aluminum oxide. Air pressure 30 to 90 psi (207 to 621 kPa), depending on metal thickness; gun held 12 in. (305 mm) from work at angle of 60° to 90°.
	M44	Coarse matte	Air blasting with 16 to 20-mesh silica sand or aluminum oxide. Air pressure 30 to 90 psi (207 to 621 kPa), depending on metal thickness; gun held 12 " (305 mm) from work at angle of 60° to 90°.
	M45	Fine shot blast	Cast steel shot of ASTM size 70-170 applied by air blast or centrifugal force.
	M46	Medium shot blast	Cast steel shot of ASTM size 230-550 applied by air blast or centrifugal force.
	M47	Coarse shot blast	Cast steel shot of ASTM size 660-1320 applied by air blast or centrifugal force.
	M4x	Other	To be specified.

TABLE 1-4 - STANDARD DESIGNATIONS FOR CHEMICAL FINISHES

All designations are to be preceded by the letters AA, to identify them as Aluminum Association designations.

Type of Finish	Designation	Description	Examples of Method of Finishing
NON-ETCHED CLEANED	C10	Unspecified	Optional with finisher.
	C11	Degreased	Organic solvent using petroleum-based or chlorinated solvents.
	C12	Inhibited chemically	Inhibited chemical type cleaner, 4-6 oz/gal (30-45 g/L), used at 140-180°F. Cleaned(60-80°C) for 2 – 5 min with a pH between 4.5 to 8.5.
	C1x	Other	To be specified.
ETCHED	C20	Unspecified	Optional with finisher.
	C21	Fine matte	Tri-sodium phosphate, 3-6 oz/gal (22-45 g/L), used at 140°-160°F (60°-80°C) for 3-5 minutes.
	C22	Medium matte	Sodium hydroxide (caustic soda) 4-6 oz/gal (30-45 g/L), used at 130°-150°F (49°-66°C) for 5-10 minutes.
	C23	Coarse matte	Sodium fluoride, 1.5oz (11g), plus sodium hydroxide 4-6 oz/gal (30-45 g/L), used at 130°-150°F (54°-66°C) for 5-10 minutes.
	C24	Fine matte	Nitric Acid (25% vol) and hydrofluoric acid (1% vol) used at room temperature for 5 to 10 min.
	C25	Adhesion pretreatment	Sulfuric acid (98%) at 16.3% vol and 6% (wt) sodium dichromate with 0.25 oz/gal (1.9 g/L) of 2024 aluminum dissolved used at 140°-158°F (60°-70°C) for 9 to 30 min.
	C26	Desmut	Nitric acid, 25-50% by vol used at room temperature for 1-6 min (hydrofluoric acid can be added [1-5% vol]).
	C27	Desmut	Chromic acid, 13.35 oz/gal (100 g/L) plus sulfuric acid, 8 oz/gal (60 g/L) plus ammonium bifluoride 0.4 – 0.67 oz/gal (3-5g/L) used at ambient temperature for 1 to 6 min.
	C28	Etched designs	Ferric chloride (42% Be), 50% (vol) used at room temperature.
	C2x	Other	To be specified.
BRIGHTENED	C30	Unspecified	Optional with finisher.
	C31	Highly specular	Immersed in 73-83% (vol) phosphoric acid and 2-5% (vol) nitric acid (and additions of 0.01% copper and 10-12% aluminum phosphate) at 194°F (90°C) for 15 sec to 5 min.
	C32	Diffuse bright	Etched finish C22 followed by brightened finish C31.
	C33	Highly specular	Immersed in 15% phosphoric acid, 70% sulfuric acid used at 185°F (85°C) for 20 min with an applied current density of 140 asf (15 A/dm ²).
	C3x	Other	To be specified.
CHEMICAL COATINGS	C40	Unspecified	Optional with finisher.
	C41	Acid chromate-fluoride	Proprietary chemicals treatments of the following general makeup used producing clear to typically yellow colored surfaces – chromic acid (3.4 - 4.0 g/L) plus sodium dichromate (3.0 – 3.5 g/L) plus sodium fluoride (0.8 g/L) used at 86°F (30°C) for 3 min.
	C42	Acid chromate-fluoride-Phosphate	Proprietary chemical treatments of the following general makeup used producing clear to typically green colored surfaces – phosphoric acid (75%), 24 g/L plus sodium fluoride, 5 g/L plus chromic acid, 6.8 g/L.
	C43	Alkaline chromate	Proprietary chemical treatments used producing clear to typically gray colored surfaces
	C44	Non-chromate	Proprietary chemical treatments of the following general makeup, using no chromates. Example 1: Potassium fluozirconate (K ₂ ZrF ₄), 0.4 g/L plus ortho-boric acid (H ₃ BO ₃), 5.0 g/L plus potassium nitrate, KNO ₃ , 10 g/L plus nitric acid (HNO ₃), 0.4 mL used at 50° – 65°C for 5 to 15 min. Example 2: Zinc oxide, 10.2% wt plus nickel oxide, 1.85% plus phosphoric acid (75%), 44.3% plus nitric acid, 4.5% plus hydrofluoric acid (70%), 0.97% plus fluorosilic acid (35%), 4.2% used at 50°-65°C for 5 to 15 min.
	C45	Non-rinsed chromate	Proprietary chemical treatments in which coating liquid is dried on the work with no subsequent water rinsing.
	C46	Non-rinsed non-chromate	Proprietary chemical treatment in which coating liquid is dried on the work with no subsequent water rinsing.
	C4x	Other	To be specified.

TABLE 1-5 - STANDARD DESIGNATIONS FOR ANODIC COATINGS

All designations are to be preceded by the letters AA, to identify them as Aluminum Association designations.

Type of Finish	Designation	Description	Examples of Method of Finishing
GENERAL	A10	Unspecified	Optional with finisher.
	A11	Preparation for other applied coatings	0.1 mil (3um) anodic coating produced in 15% H2SO4 used at 70° ± 2°F, (21° ± 1°C) 12 amp/sq ft (129 A/m2) for 7 minutes, or equivalent.
	A12	Chromic acid anodizing coatings	To be specified. Example 1: chromic acid (2.5 – 3%) at 40°C at 0.1 – 0.5 A/dm2 for 5 to 30 min to produce a 2 - 15 um (0.1 – 0.6 mil) coating.
	A13	Hard, wear and abrasion resistant coatings	To be specified. Example 1: sulfuric acid (130 g/L) plus oxalic acid (14 g/L) used at 48 – 52°F at 36 asf for 20 min to produce a 1 mil coating.
	A14	Non-chromate adhesion pretreatment	To be specified. Example 1: Phosphoric acid (10%) used at 23 - 25°C at 10-12 V for 20 to 30 min to produce a 1-2 um (<0.1 mil) coating.
	A1x	Other	To be specified.
PROTECTIVE AND DECORATIVE (Coatings less than 0.4 mil thickness)	A21	Clear coating	Coating thickness to be specified. 15% H2SO4 used at 70° ± 2°F (21° ± 1°C), 12 amp/sq ft (129 A/m2).
	A211	Clear coating	Coating thickness - 0.1 mil (3um) minimum. Coating weight - 4 mg/in2 (6.2 g/m2) min.
	A212	Clear coating	Coating thickness - 0.2 mil (5um) minimum. Coating weight - 8 mg/in2 (12.4 g/m2) min.
	A213	Clear coating	Coating thickness - 0.3 mil (8um) minimum. Coating weight -12 mg/in2 (18.6 g/m2) min.
	A22	Coating with integral color	Coating thickness to be specified. Color dependent on alloy and process methods.
	A221	Coating with integral color	Coating thickness - 0.1 mil (3um) minimum; Coating weight - 4 mg/in2 (6.2 g/m2) min.
	A222	Coating with integral color	Coating thickness - 0.2 mil (5um) minimum; Coating weight - 8 mg/in2 (12.4 g/m2) min.
	A223	Coating with integral color	Coating thickness - 0.3 mil (8um) minimum; Coating weight - 12 mg/in2 (18.6 g/m2) min.
	A23	Coating with impregnated color	Coating thickness to be specified. 15% H2SO4 used at 70° ± 2°F (21° ± 1°C), 12 amp/sq ft (129 A/m2) followed by dyeing with organic or inorganic colors.
	A231	Coating with impregnated color	Coating thickness - 0.1 mil (3um) minimum; Coating weight - 4 mg/in2 (6.2 g/m2) min.
	A232	Coating with impregnated color	Coating thickness - 0.2 mil minimum; weight - 8 mg/in2 (12.4 g/m2) min.
	A233	Coating with impregnated color	Coating thickness - 0.3 mil minimum; weight - 12 mg/in2 (18.6 g/m2) min.
	A24	Coating with electrolytically deposited color	Coating thickness to be specified. Application of the anodic coating, followed by electrolytic deposition of inorganic pigment in coating.
	A2	Other	To be specified.
ARCHITECTURAL CLASS II (Coatings with 0.4 to 0.7 mil thickness)	A31	Clear (natural)	15% H2SO4 used at 70° ± 2°F (21° ± 1°C), 12 amp/sq ft (129 A/m2) for 30 min, or equivalent.
	A32	Coating with integral color	Color dependent on alloy and anodic process.
	A33	Coating with impregnated color	15% H2SO4 used at 70° ± 2°F (21° ± 1°C), 12 amp/sq ft (129 A/m2) for 30 min, followed by dyeing with organic or inorganic colors.
	A34	Coating with electrolytically deposited color	Application of the anodic coating, followed by electrolytic deposition of inorganic pigment in coating.
	A3x	Other	To be specified.
ARCHITECTURAL CLASS I (Coatings of 0.7 mil or greater)	A41	Clear (natural)	15% H2SO4 used at 70° ± 2°F (21° ± 1°C), 12 amp/sq ft (129 A/m2) for 60 min, or equivalent.
	A42	Coating with integral color	Color dependent on alloy and anodic process.
	A43	Coating with impregnated color	15% H2SO4 used at 70° ± 2°F (21° ± 1°C), 12 amp/sq ft (129 A/m2) for 60 min, followed by dyeing with organic or inorganic colors.
	A44	Coating with electrolytically deposited color	Application of the anodic coating, followed by electrolytic deposition of inorganic pigment in coating.
	A4X	Other	To be specified.

REFERENCES

For more detailed information on the subject of finishes for aluminum the following references can be contacted for their publications:

Aluminum Anodizers Council (AAC), 1000 North Rand Road, Suite 214, Wauconda, Illinois 60084.

The Aluminum Association (AA), 900 19th Street, NW, Washington, DC 20006; www.aluminum.org.

Aluminum Company of America (ALCOA), 201 Isabella Street, Pittsburgh, PA. 15212 Technical Center, 100 Technical Drive, Alcoa Center, PA 15069; www.alcoa.com.

American Architectural Manufacturers Association (AAMA), 1827 Walden Office Square, Schaumburg, IL 60173; www.aamanet.org.

American Society for Metals (ASM International), 9639 Kinsman Road, Materials Park, OH 44073-0002; www.asm-intl.org.

Architectural Metals, L William Zahner, John Wiley and Sons, New York, NY.

Builders Hardware Manufacturers Association (BHMA), 355 Lexington Avenue, 17th Floor, New York, NY 10017; www.buildershardware.com.

Electroplating Engineering Handbook, Van Nostrand Reinhold Publishing Corp., New York, NY.

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FINISHES FOR THE COPPER ALLOYS

General

Among the architectural metals, the copper alloys are unique in that they are the only ones possessing integral color. Natural colors vary, depending on the alloy used, ranging from the salmon pink of alloy 110 (copper), through the golden yellows of alloys 385 (Extruded Architectural Bronze), 280 (Muntz Metal) and 230 (Red Brass) to the warm whites of the nickel silvers. The natural color range is augmented by the effects of weathering; patinas or verdigris on antiques; and statuary or oxidized finishes achieved either by exposure to the elements or by accelerated means.

Originally the term “bronze” was applied only to copper-tin alloys, and the term “brass” to alloys of copper and zinc, but this distinction no longer holds. There is now no definite dividing line between these two general classes of the copper-base alloys.

Architects and architectural metal fabricators in common have, for years, referred to the principal architectural alloys of copper as “bronzes” despite the fact that of the five principal alloys so used, none contain tin and three of them, in fact, are true brasses. There is some justification for this, however, since the alloys 230 (Red Brass), 280 (Muntz Metal) and 385 (Extruded Architectural Bronze) do resemble tin bronze architectural castings in color, in both the natural and weathered states.

In the natural finish they are dubbed simply “yellow bronze”; in the intermediate brown weathered states, “statuary bronze”; and in the final weathered or patinated condition, “green bronze”. Similarly, the nickel silver alloys are often referred to as “white bronze”. In the acknowledgement of this long established custom, therefore, the term “bronze” will generally be used to designate all of these alloys, with the realization that two, three, or even more distinct alloys are frequently required in order to complete a given architectural composition. The common finishes for “bronze” are listed on page 2-3.

Just as with aluminum, many of the finishes listed in the preceding Summary are, as indicated, sup-

plied by processors or product manufacturers, rather than by the prime producers of the metal. The only true end-use finishes supplied at the mill, for architectural work, are the “As Fabricated” finishes; all of the others are referred to as process finishes, being supplied after the metal leaves the mill.

Fastener alloys generally used are 220 (Commercial Bronze, 90%) and 260 (Cartridge Brass, 70%). A Unified Numbering System (UNS) for metals and alloys developed by ASTM and SAE has been applied to copper alloys and is administered by CDA. To utilize the UNS system, simply prefix the present CDA alloy numbers by the letter C and add a suffix 00. Thus, for example, copper alloy No.385 becomes C38500 in the UNS system.

Mechanical Finishes

Mechanical finishes are those that involve the use of no chemical or electrochemical treatment and no additive, but provide a surface texture by mechanical means alone. These textures vary widely in character and range from the surface appearance resulting from the various production processes to highly reflective surfaces produced by successive grinding, polishing and buffing operations. Costs vary in proportion to the amount of processing required.

“As Fabricated” Finishes

The term “As Fabricated” refers either to the metal stock or to a fabricated product. As a finish designation for copper alloy stock it refers to the surface appearance and texture imparted to the metal by the rolling mill, extrusion press, or casting mold that shapes it. Subsequent fabrication operations on the copper alloy, such as forming, sawing, punching, drilling, milling, etc., including scratches, can mar the “as fabricated” finish. Under some conditions the marring can be corrected by simple mechanical deburring and smoothing. For other conditions the marring can result in an unacceptable “as fabricated” mechanical finish, and a subsequent finishing operation will be required and should be specified.

Summary of Typical Copper Alloy Finishes

Finish	Copper Development Ass'n Finish Designation (see page 2-11)	Finish Normally Supplied By			Relative Costs (on flat surfaces)
		Mill	Process- sor	Fabricator or Finisher	
MECHANICAL					
As Fabricated	M10 Series	X			base
Buffed	M20 Series			X	medium to high
Directional Textured	M30 Series			X	low to medium
Non-Directional Textured	M40 Series			X	medium
Patterned	M4x (Specify)	X	X		low to medium ¹
CHEMICAL					
Cleaned only	C10 Series	X		X	base or low ²
Matte Dipped		X			base or low ²
Bright Dipped		X			base or low ²
Conversion Coatings	C50 Series			X	medium to high
COATINGS (see <i>Applied Coatings, Chapter 5</i>)					
Organic: Air Dry	060 Series			X	low to medium
Thermo-set	070 Series			X	low to medium
Chemical Cure	080 Series			X	low to medium
Vitreous			X		high
Laminated	L90 Series		X		medium to high
Metallic			X		medium to high

The term PROCESSOR, as used here, refers to a "middleman" between the mill and the fabricator, who applies coatings, textures or other finishes to metal bulk form, generally cut sheet or strip or coil stock. FABRICATOR refers to the producer of stock metal shapes or the manufacturer of the end-use product. He either provides the final finish or sends the fabricated product to a finisher who does this work. The FINISHER does not usually fabricate products but provides finishes, as specified, to products fabricated by others.

The RELATIVE COSTS indicated are necessarily approximate, for general guidance only. Exact costs vary considerably with quantity, type of product, method of application, quality of work, and other influences, and should always be verified.

¹ Certain embossed patterns, because of their stiffening effect, permit the use of thinner metal; and this saving can, in some cases, offset their cost. In other cases, patterned finishes involve extra costs.

² Pricing practice for these finishes varies with different prime producers.

"As Fabricated" mechanical finishes, as a class, are the simplest and least expensive obtainable. Such finishes can be quite acceptable for architectural applications and are widely used. Typical of these are specular "as fabricated" cold-rolled sheet and non-specular "as fabricated" extrusions. Highly polished rolls used at the mill for the final pass provide the specular finish on the cold rolled sheet. Carefully machined and well-maintained dies for the extrusion press ensure extruded surfaces free of objectionable die marks or striations.

These finishes vary somewhat, according to the metal-forming process used. Hot-rolled and heat-treated products have a comparatively dull surface finish and show a certain amount of darkening or discoloration, while cold-rolled surfaces have a brighter and more metallic color. Extruded products have an intermediate appearance somewhat resembling that of the cold-rolled items, and can have detectable surface striations caused by the extrusion die, while castings have a rougher matte finish.

The following are the typical variations of the "As Fabricated" finish:

- Unspecified:** This is the uncontrolled natural finish produced by extrusion, casting, hot-rolling, or cold-rolling with unpolished rolls. On rolled products it can vary from dull to rather bright and have stains or light films of rolling oil.
- Specular:** A mirror-like cold-rolled finish, produced on one or both sides of the sheet by final passing through highly polished steel rolls.
- Matte:** A dull finish produced by hot-rolling, extruding, casting or cold-rolling, followed by annealing.

Polished / Buffed Finishes

These are process finishes, applied by the product manufacturer, and are produced by successive processes of grinding, polishing, and buffing. Because they require a series of operations, they are more expensive than other mechanical finishes, their cost generally being proportional to

the smoothness and brightness provided.

Except for hardware items, fixtures, and occasional highlighting of extruded shapes, these finishes have only limited application to architectural products. Because of their high reflectivity, they should not be used on wide flat surfaces.

Among the many variations possible, two types are generally considered as standards:

- a) **Smooth specular (mirror-like):** This is the brightest mechanical finish obtainable and is produced by first polishing, then buffing. Polishing is an abrading operation that smooths the surface by removing a certain amount of metal. It is usually accomplished in several stages, using abrasive belts or polishing wheels of cloth, felt, or leather, with compounds containing fine aluminum oxide or silicon carbide abrasives. Coarser abrasives are used in the first stages, but final polishing is done with 320 or finer grits. The subsequent buffing process produces a smooth and lustrous surface, removing relatively little metal, but often producing an actual flow of the surface film under the frictional heat developed. The buffing wheels are usually made of stitched muslin discs, and the buffing compounds used consist of very fine abrasives in a suitable binder.
- b) **Specular:** This is a finish of somewhat lesser brightness and is provided by the polishing procedures described above, with some subsequent buffing, but not necessarily sufficient to remove all evidence of scratches and/or other surface imperfections.

Directional Textured Finishes

These are among the most common and popular of the process finishes used on architectural bronze, providing a smooth satiny sheen of limited reflectivity. Their characteristic soft texture results from tiny, nearly parallel scratches in the surface of the metal produced by wheel or belt polishing with fine abrasives, by hand rubbing with stainless steel wool, or by brushing with abrasive wheels.

In belt polishing, the fineness of the finish is controlled by the size of the grit used, the speed of the belt, the hardness of the block or pad used, the pressure exerted on the block, and the condition of the belt.

There are six standard variations of this type of finish:

- a) **Fine satin**
 - b) **Medium satin**
 - c) **Coarse satin**
 - d) **Uniform**
- } Produced by wheel or belt polishing with aluminum oxide or silicon carbide abrasives ranging from 240–320 grit for fine satin to 60–80 grit for uniform, using a peripheral speed of approximately 6,000 ft/min (30 m/s).
- e) **Hand rubbed:** Usually provided by rubbing with No. 0 pumice and solvent on a fine brass wire brush or non-woven abrasive mesh pad. This is a relatively expensive finishing process, and is used only where the nature of the work makes other methods impractical. It is frequently employed, however, to even out and blend in satin finishes produced by other means.
 - f) **Brushed:** Coarser directional finishes are produced by using power-driven wire wheel brushes; brush-backed sander heads (Vonnegut wheels), abrasive-impregnated foamed nylon discs (Scotch-Brite®), or abrasive cloth wheels (PG wheels). The wire wheel brushes have wires of stainless steel, brass, or nickel silver; and the degree of fineness is determined by the diameter of the wire, speed of the wheel, and the pressure exerted on the work.

Non-Directional Textured Finishes

These are matte finishes of varying degrees of roughness, produced by spraying sand or metal shot against the metal under controlled conditions. Their principal use in architectural work is on items produced by casting.

The texture of the surface is determined by the size and type of abrasive used, the amount of air pressure, and the position and movement of the nozzle. The finer the abrasive, the smoother the finish. A comparatively rough finish is produced by using coarse silica sand, while the smoothest finishes result from dust blasting with a very fine abrasive or from “vapor honing” with a slurry of extremely fine abrasive and water.

It should be recognized that these finishes have limited applicability to architectural work. Because the impingement of the abrasive under pressure tends to distort the metal, their use is not recommended on material less than ¼ in. (6 mm) thick. There is usually difficulty in obtaining uniform appearance unless special equipment is used to regulate pressure and nozzle movement.

Since the surface produced by even the finest abrasive is actually rough, shows fingerprints, and collects and holds dirt, some type of protective treatment is necessary to retain a clean appearance. Clear organic coatings are usually used for this purpose. In stripping such coatings, complete removal from the roughened surface can prove difficult.

Sandblasted finishes are obtained by using an air blast with silica sand or aluminum oxide or different degrees of fineness that range from #100-#200 mesh for fine texture to #20 mesh for coarse.

The three standard grades of fineness for sandblast finishes are:

- a) **Fine matte**
- b) **Medium matte**
- c) **Coarse matte**

Shot blasting is used to provide peened and burnished finishes that are generally less rough than sandblasted finishes. Shot blasted finishes are obtained by using an air blast with metal shot ranging in size from S-70 for fine texture to S-550

PRECAUTIONS

Regarding the Use of Mechanical Finishes on Copper Alloys

An "As Fabricated" finish is the finish on the metal as it is received from the rolling mill, roll former, extrusion press, or casting mold, prior to any further mechanical, chemical, organic, or vitreous finishing operation. In many architectural applications this finish will be acceptable without further mechanical finishing. However, in some products, fabrication operations subsequent to the original as fabricated finish, such as forming, sawing, punching, drilling, milling, etc., can mar the finish so that it is not satisfactory for architectural applications. For such products it is necessary to perform additional mechanical finishing operations, and these should be specified.

Smooth specular finishes are shop applied by processing methods that are virtually impossible to use in the field. The use of this type of finish in traffic areas where the surface can be subject to marring must be avoided.

Specular finishes are shop applied also. Refinishing can be accomplished in the field, but it necessitates the use of expensive hand methods. These finishes should therefore be used only in areas where exposure to marring is minimal.

For areas not subject to close inspection, the cost of a satin finish is often not justified. An appropriate alternate is a low cost "uniform finish" (No. M36, Table 2-3) that can be applied by belt sanding in a single pass and is quite popular on extrusions, tubes and roll-formed shapes.

The appearance of waviness and buckling in large flat areas ("oil canning") can be minimized by specifying the use of matte or textured finishes or contoured surfaces. Another option is to use thicker material. Stretcher leveled and re-squared sheet also helps minimize "oil-canning." Highly polished or buffed finishes, on the other hand, tend to magnify such irregularities and should be used only on relatively small areas, or where "oil canning" is desired or not a concern.

Sandblasted or shot blasted finishes should not be specified for thin sheet, tube, or extrusions, because of the distortion usually caused by applying such finishes.

Because of difficulties encountered in maintenance, wire brushed finishes should be limited to small areas or highlighting.

All surface protective coverings such as adhesive paper and strippable plastic films should be removed as soon as possible after installation because they tend to become difficult to remove under exposure to sunlight and weather.

for coarse. The three standard grades of fineness for shot blast finishes are:

- a) **Fine shot blast**
- b) **Medium shot blast**
- c) **Coarse shot blast**

Patterned Finishes

Patterned finishes are also available in thin sheet, in a wide variety of sculptural designs and textures. These are produced by passing “as fabricated” sheet either between two machined matched-design rolls, impressing patterns on both sides of the sheet (embossing), or between a design roll and a smooth roll, “coining” one side of the sheet only. The embossing process usually increases the stiffness of the sheet, eliminates distorted reflections, and minimizes marring in service. Such patterned sheets are supplied by some mills and by secondary processors.

Chemical Finishes

Among the most important finishes for the copper alloys are those produced by chemical treatments. Such finishes are obtained by washing or dipping the fabricated product in chemical solutions that can be proprietary in nature, or by spraying or swabbing such solutions on the metal surface. In general, these processes have any of four principal purposes:

- to merely clean the surface, without otherwise affecting it,
- to provide a matte textured surface (by etching),
- to produce a smooth bright finish, or
- to chemically convert the surface film, changing the surface color of the metal and, at the same time, providing a final finish.

Some of these are not true finishes, but only intermediate steps in an overall finishing process. The matte and bright chemical finishes for copper alloys find relatively few architectural applications, the former in particular being used far less extensively than on aluminum. The conversion coatings, however, are of major importance and generally do provide final finishes.

Non-etch cleaning

Several types of chemical treatment are used to thoroughly clean copper alloys before applying

other finishes. They have no physical effect upon the surface of the metal, and cannot be classed as true finishes, but they produce a chemically clean surface that is free of all foreign matter such as oil, grease, fingerprints and soil of any kind.

Two such chemical cleaning methods are commonly used:

- a) **Degreasing:** Vapor degreasing exposes the metal to vapors from chlorinated solvents such as trichloroethylene and perchloroethylene. Special degreasing machines are used either as a batch method or as part of a continuous processing line. Solvent or solvent emulsion cleaning, with hydrocarbon solvents, is used to remove oil and greases from the metal surface and is less expensive than vapor degreasing. To achieve maximum cleanness, degreasing of any type should be followed by chemical cleaning.
- b) **Chemical cleaning:** This method is used when mineral and animal fats and oils must be removed. The metal can be sprayed with, or immersed in, any of a number of proprietary or non-proprietary solutions, usually at elevated temperatures; and then rinsed with water. Only *inhibited* chemicals are used on the copper alloys; the solutions used on ferrous metals are not appropriate because they attack the metal. Some of these inhibited cleaners use as their base a variety of newly developed alkalis and soaps such as sodium tetraborate, disodium phosphate, sodium silicate, and soaps made from various vegetable and animal oils, often with the addition of a wetting agent.

Matte Finishes

Although etched finishes are widely used for architectural aluminum, the term “etching,” as used in the copper industry, usually refers to the process of producing surface designs or patterns by selective etching, rather than a type of overall finish. Overall matte finishes, referred to as “matte dipped” finishes, are produced on the copper alloys by chemical means and usually applied after first “bright dipping” the item. Such matte finishes are seldom used, however, on the architectural alloys of copper.

Bright Finishes

Bright dipped finishes also have only limited architectural application, being used chiefly to

prepare the surface for other finishing operations such as plating, or to improve the adherence of paint. They are produced by immersion in solutions of sulfuric acid and nitric acid with a small quantity of water and hydrochloric acid.

Conversion Coatings

The most interesting, and probably the most important, finishes for the copper alloys are the conversion coatings. They serve to chemically “convert” the surface film of the metal. In contrast to their typical uses on the other architectural metals, the principal function of these treatments, as used on the “bronzes,” is not simply as a pre-treatment for applied coatings, but to alter the surface color of the metal and, at the same time, provide the final finish. Their purpose is often to duplicate, by accelerated chemical means, the natural weathered effects generally resulting after the metal is exposed to the elements from one to twelve years. Unfortunately, these processes depend largely upon art and craft techniques and are not wholly adequate to meet the current demand for uniform and economical coloring of large surface areas. There is a recognized need either to improve them or preferably to replace them with controlled, semi-automated processes.

These conversion treatments are of two general types: those producing the patinas or verdigris, and those producing the statuary or oxidized colors.

The **patinas**, in particular, are somewhat difficult to control, because successful generation of the conversion coatings is dependent upon a number of variables including temperature, humidity, surface condition of the metal, and method of application. Variations in color are not uncommon, and uniform coating development over large surface areas cannot be readily controlled. A true natural patina on close inspection is not fully uniform. A fully “uniform” conversion coating might be considered “unrealistic” if meant to simulate a naturally weathered surface. Patinated finishes are normally intended for non-traffic areas and in locations where little or no maintenance is required. Clear organic coatings can be applied to improve wear resistance in traffic areas but such applied coatings tend to alter the patina color.

In general, **patinas** are produced by the action of various chloride salts. A few processes employ sulfate-chloride or chloride-carbonate combina-

tions. Among the most common of these processes are the following:

- a) **Acid chloride treatments** develop the chloride salts of copper by use of a saturated solution of sal ammoniac in water, applied by brush or spray, or a cuprous chloride-hydrochloric acid solution, applied by spray or sponge.
- b) **Acid sulfate treatments** generally use the ammonium sulfate solution developed by the Copper and Brass Research Association. This is applied by spray, in a series of coatings, to produce the desired patina density.
- c) **Carbonate treatments** employ various carbonate solutions and are normally mill or process applied. These are seldom used for architectural work.

Note: Due to the popularity of the appearance of an “aged” patina look on copper, and traditional difficulty in achieving this appearance on exposed copper by field applied means, some copper mills are currently producing factory patinated sheet copper through proprietary methods.

Statuary bronze finishes are usually obtained by formation of a surface film of cuprous oxide or a mixture of copper sulfides. The ultimate appearance of the various statuary finishes is critically influenced by such factors as the natural color of the substrate (i.e. the alloy employed), the coarseness or fineness of the mechanical finish on the substrate, and the thickness of the translucent conversion film. Color uniformity depends entirely on the physical homogeneity and chemical cleanliness of the metal surface prior to the actual coloring operation. Statuary bronze finishes can be highlighted by cutting back the conversion coating with an abrasive. The toning achieved by this method can vary from a light golden color to black. Protection of highlighted finishes is desirable since the highlights disappear as the metal oxidizes (tarnishes).

The three most common coloring treatments of this type are:

- a) **Oxide treatments** develop the characteristic statuary brown colors through formation of cuprous oxide. Potassium permanganate and copper salt solutions are commonly used. Ox-

ide treatments are seldom used for architectural work because of their relative instability.

- b) **Sulfide treatments** produce the statuary brown colors by various aqueous sulfide solutions. Common solutions of this type are potassium sulfide (liver of sulfur), sodium sulfide

(liquid sulfur) and ammonium sulfide. Antimony pentasulfide (paste) is also used.

- c) **Selenide treatments** provide deep colors with fast acting selenide solutions. These solutions are toxic and must be handled with care.

PRECAUTIONS

Regarding the Use of Chemical Finishes on Copper Alloys

Neither matte dipped nor bright dipped finishes should be specified as final finishes. Uniformity is difficult to control in these finishes, and they are normally used as “in process” operations to prepare the surface for further finishing.

The appearance of statuary finishes is impaired by dirt, mill scale and fingerprints. Such disfigurations are magnified by the conversion process. Welding and brazing should be limited to concealed areas wherever possible, since weld and braze areas tend to color at different rates than the base metal.

Chemically produced statuary finishes are usually hand applied and require skilled artisans to achieve a uniform finish. Therefore, they tend to be difficult as well as expensive to produce and maintain.

For maintenance of statuary finishes, periodic rubbing with oil is generally recommended. If clear organic coatings were used to protect the original finish, care must be exercised in stripping the coating prior to re-oiling in order to avoid marring the conversion film.

All surface protective coverings such as adhesive paper and strippable plastic films should be removed as soon as possible after installation, because they tend to become brittle and unpeelable under exposure to sunlight and weather.

Clear Organic Coating Finishes

Applied organic coating finishes differ from mechanical and chemical finishes in that they serve their purpose by adding some form of covering, rather than by physically or chemically affecting the surface of the metal itself. Applied coatings applicable to all architectural metals are thoroughly treated in Chapter 5. However, because of the importance of selecting appropriate coatings for preserving the finishes on copper alloys, they are briefly reviewed here.

Clear organic coatings are essentially synthetic resins, natural resins, oils, or combinations of these in solvent solutions that either dry at ambient temperature or are heat cured to hasten solvent evaporation. They are designed to preserve the natural color of the copper alloys by providing a tough, thin barrier layer on the metal surface that effectively retards superficial tarnishing caused by weathering and handling. For most large scale architectural applications, air-dry coatings predomi-

nate, because it is impracticable to heat cure such coatings in situ at such time as coating renewal is required. In general, baked coatings tend to be more durable and resistant to abrasion and chemical attack than their air-dry counterparts. As might be expected, they are also more difficult to strip.

INCRALAC is a clear organic air-drying acrylic lacquer for field or shop coating of copper and copper alloys. In research initiated by the International Copper Research Association (INCRA), INCRALAC provided the best protection of all air-dry coatings tested.

When applied to a properly cleaned metal surface, INCRALAC provides excellent protection indoors. Although some protection is provided on exterior applications, periodic maintenance of the clear coating is required and should be taken into consideration.

The use of abrasive pads followed by washing with a cleaning solvent provides a surface for maximum performance. Steel wool should not be

used because it sometimes contains a corrosion inhibitor that can cause discoloration later. If abrasive pads are not available the surface should be thoroughly washed with a solvent or alkali cleaning solution, or by vapor degreasing. INCRALAC is designed for spray application and should not be brushed. Conventional spray equipment can be used, applying first a mist coat, followed by a wet coat. Two coats are recommended with at least 30 minutes air dry between coats. For some products, where spraying is not entirely satisfactory, dipping is an alternate method of application.

Other widely used clear coatings for both interior and exterior applications include the nitrocellulose lacquers. They are easy to apply and strip. Their chemical resistance is fair and their exterior durability limited so that they are normally renewed yearly. Nitrocellulose coatings are frequently modified with alkyd and acrylic resins in order to improve both durability and abrasion resistance.

Alkyd resins blended with melamine resins produce coatings with good chemical resistance and with durability satisfactory for exterior applications. Like the nitrocellulose coatings, the melamine modified alkyd coatings are relatively low cost. Unmodified alkyd coatings are seldom used.

Acrylic coatings provide good color retention and resistance to chemicals, impact, and abrasion. They are widely used for both exterior and interior architectural applications but are somewhat higher in cost than the previously discussed coatings.

Clear epoxy coatings exhibit excellent resistance to chemicals, impact, and abrasion. Their use on architectural components is limited by the fact that these coatings are only produced in heat cured or chemical catalyst cured formulations. The clear epoxies are primarily interior coatings. They tend to chalk and darken when exposed to the weather.

Color stable, low gloss, modified urethane coatings that retain the excellent chemical and abrasion resistance afforded by the urethane resins are available.

Pigmented coatings are sometimes employed by fabricators and metal maintenance firms to simulate the natural weathered or chemically induced statuary brown colors. Such simulations seldom achieve the desired result since they lack the subtle shading associated with both the natural and chemically induced statuary finishes.

Care and Maintenance of Finishes

Brown Statuary

Regularity is the key to a successful maintenance program. A schedule should be arranged providing periodic cleaning with regular inspections in the interim. The schedule should differentiate between interior and exterior surfaces, and those surfaces subject to handling, scuffing, and abrasion. When a regular maintenance program is followed, most installations can be maintained by oiling or waxing. Some can be maintained by lacquering and a few, by polishing.

Surfaces pre-finished or naturally weathered to the statuary bronze shades should be maintained by periodic oiling with Lemon Oil, U.S.P.; Lemon Grass Oil, Native E.I.; or a high grade paraffin oil.

Mixtures of Carnauba wax and wood turpentine, or beeswax and wood turpentine, as well as quality commercial paste waxes, have been found satisfactory. The costs of waxing versus oiling should be compared.

Oil and wax coatings look best when applied with a well-impregnated, clean, soft cloth followed by rubbing with a second clean, soft cloth to remove excess oil or wax. Frequency of oiling or waxing is as important as the oil or wax used. Newly installed metal should be oiled weekly for the first month in order to build up a protective film. Metals subject to heavy traffic should be oiled or waxed at one to two week intervals. Where traffic is moderate to light, monthly treatment is usually sufficient. In non-traffic areas, quarterly or semi-annual applications are feasible.

At a typical building entrance, door handles, push plates or bars, kick plates, and the door stiles and rails would normally be exposed to heavy traffic. The doorframe and adjacent window wall framing usually receive less handling and would be considered a moderate to light traffic area. Transoms, canopies, and similar metal elements normally out of reach would be classed as non-traffic areas.

To restore statuary finishes, the surfaces can be cleaned with a 5% oxalic acid and water mixture together with a finely ground India pumice powder. Wipe dry with soft clean cloths and apply the coloring solution.

Bronze and other copper alloys can be restored to their original appearance even after years of neglect. Restoration of neglected surfac-

es can require the advice of specialists engaged in maintenance work.

Green Patina

Copper, brass, and bronze are resistant to destructive corrosion. The patina that forms naturally is a protective film.

No maintenance is required for an existing natural patina or one that is in the process of formation.

If a natural statuary finish is desired on copper, weathering can be arrested at the desired point by applying a suitable oil, e.g. raw linseed oil or lemon oil.

Depending on the prevailing climatic conditions and the degree of exposure, the frequency of oiling can be at intervals of from one to three years. Instances have been recorded where the initial oiling applied in two thin coats has preserved the statuary finish in excess of ten years.

PRECAUTIONS

Regarding Color Uniformity of Copper Alloy Finishes

Standard finishes for Builders' Hardware. Owing to the differences in the processes of producing these finishes and the variety of metals to which they are applied, it is impractical to attain an exact match. A standard finish from two or more sources will compare reasonably when the items are viewed at arm's length and approximately 2 ft (0.6 m) apart.

Oxidized finishes represent the natural aging of metals and change with time. Therefore some variations from standard can be expected. Artificially produced finishes do not necessarily match finishes produced by natural aging. Statuary bronzes, BHMA 623 and 624 (US20 and 20A), are more difficult to produce in a given color (shade or tone) than any other standard finish, including other oxidized finishes.

Sources of copper alloys can be domestic producers or foreign producers. In meeting a fabricator's order the supplier delivers the items ordered in the alloy specified but the items can be from different sources. Chances for variations in the alloy are increased under these circumstances, and these variations can result in the inability of the fabricator or the finisher to obtain the color uniformity desired by the architect. Chances of acceptable color match are much better if all material is from the same source.

Color of bronze will change with time and will change differently with different exposures.

Treatments that provide green patinas and brown statuary finishes are influenced by a number of factors that makes exact color uniformity difficult if not impossible to attain.

Standard color samples can change over time thereby changing the reference to which a finisher is working.

Extruded and rolled shapes and plate do not have the same color tones even though they are produced from the same alloys. Similarly, cast and forged items can have different appearances.

The fabricator of architectural bronze products must be aware of these potential problems with color and appearance.

Standard Finish Designations

For many years, the US Finishes Designation System has been used by architects as well as manufacturers, especially in federal work, for specifying finishes to be used on brass and bronze. This system was primarily intended for identifying finishes for hardware. It was generally found to be inadequate for designating the broad range of finishes used in architectural work.

The Department of Commerce, Commercial

Standard CS22-40, that defined US finishes, was dropped after World War II, and the National Bureau of Standards was no longer a source for standard finish samples. Hardware manufacturers, however, continued to use the US designations in their catalogs. Ultimately individual manufacturers established their own interpretations of US finishes and provided their own standard samples. Thus, there are not any truly national US finish standards. The Builders Hardware Manufacturers

Association (BHMA) has established its designations for hardware finishes and has listed the nearest US equivalents of BHMA numbers in American National Standard for Materials and Finishes, ANSI/BHMA A156.18-2000. BHMA has samples of selected finishes available.

Hardware made of brass and bronze, however, is extensively used with architectural products. Finishes on hardware items are now generally designated by finish code numbers of the BHMA. A variety of finishes is available. Table 2-1 shows those most commonly used today. Since U.S. Finish Designations occasionally appear in specifications, the nearest U.S. equivalent of the BHMA number is shown on the list. For a complete listing and description of hardware finishes refer to ANSI/BHMA A156.18-2000.

Specifiers sometimes use the polished finish designations for stainless steel shown in Finishes for Stainless Steel, Chapter 3. While these finishes are applicable to copper alloys, the use of stainless steel designations can cause confusion and is discouraged.

To provide for a better method of identifying architectural finishes, the Copper Development Association, in 1967, adopted a designation system similar to that established several years previously by the Aluminum Association. Many of the finishing processes and effects used on all of the non-ferrous metals are basically the same. The use of a similar identification system, therefore, is

not only logical, but greatly simplifies the work of the architectural specifier in recognizing the similarities and differences.

Four categories are included in this system, representing the most common types of finish -- mechanical finishes, chemical finishes, clear organic coatings and laminated coatings -- each being designated by a different letter as follows:

Mechanical FinishesM
Chemical FinishesC
Clear Organic CoatingsO
Laminated CoatingsL

The designation for any specific finish in any of these categories will consist simply of a letter followed by two digits. Table 2-2 summarizes the designation system.

Only broad classifications have been proposed for the various types of coatings. All of the more common finishes in both the mechanical and chemical categories, however, have been assigned specific symbols; and these are shown in Tables 2-3 and 2-4 respectively. The descriptions of finishes listed in these tables, under the heading "Examples of Methods of Finishing," are only suggested means of obtaining them; alternate methods of producing equivalent finishes are acceptable in all cases.

Explanation of the Use of the System

A simple finish requires only a single designa-

TABLE 2-1 — FINISHES FOR BRASS AND BRONZE HARDWARE

Code No.	Description	Nearest US Equivalent
605	Bright brass, clear coated	US3
606	Satin brass, clear coated	US4
611	Bright bronze, clear coated	US9
612	Satin bronze, clear coated	US10
613	Dark oxidized satin bronze, oil rubbed	US10B
622	Flat black coated	US19
623	Light oxidized statuary bronze, clear coated	US20
624	Dark oxidized statuary bronze, clear coated	US20A
625	Bright chromium plated over nickel	US26
626	Satin chromium plated over nickel	US26D
632	Bright brass plated, clear coated	US3

tion, but frequently two or more designations will be required to identify a sequence of finishing operations leading to a final finish on a given alloy, for example, M36-C51.

It is understood, however, that when only single designations are used, other processing steps normally followed as preparation for the specified finish can also be used at the option of the fabricator or finisher.

The use of the letter “x” in place of a second digit in all categories of the designation system (e.g., M2x, C5x, etc) indicates that no specific number, other than the general category digit, has yet been assigned to that specific finish. To identify specific “unlisted” finishes having only this general “x” designation, the designation symbol must be followed by a brief word description, as illustrated in examples 3 and 4 following:

Example 1 -- Patina Conversion Coating

To specify a chemically induced patina using the ammonium sulfate process, the following designation would apply:

M36 -- C12-C52 represents:

M36 -- Mechanical Finish, Directional Textured, Uniform (Table 2-3)

C12 -- Chemical Finish, Non-etched Cleaned, Degreased (Table 2-4)

C52 -- Chemical Finish, Conversion Coating, Ammonium Sulfate (Table 2-4)

Example 2 -- Statuary Conversion Coating over Satin Finish

To specify a medium statuary finish on items subject to close inspection, the architect would use the designation:

M32-C55 representing:

M32 -- Mechanical Finish, Directional Textured, Medium Satin (Table 2-3)

C55 -- Chemical Finish, Conversion Coating, Sulfide (Table 2-4)

Example 3 -- Natural Satin Finish, Lacquered

To produce and preserve a fine satin finish on sheet, the following designation is appropriate:

M31-M34-O6x, using “XYZ” Company’s clear acrylic lacquer No.____, applied by air spray in two full coats, with interim drying, to a total thickness of 1.0 mil.

In this designation, the symbols used signify the following:

M31 -- Mechanical Finish, Directional Textured, Fine Satin (Table 2-3)

M34 -- Mechanical Finish, Directional Textured, Hand Rubbed (Table 2-3)

O6x -- Coating, Clear Organic, Air Dry, to be specified

Example 4 -- Patterned Finish, Lacquered

Since neither the patterned (mechanical) finish nor the lacquer (organic) coating has a specific finish designation, the general symbols for these processes would be used, supplemented by a brief word description for each, and the designation for the total finish would be:

M11-- M4x-C12-O1x, using “X” Company’s Pattern No.____ and “A” Company’s Epoxy RR clear coating, applied by airless spray in two full coats with a 10-minute bake at 275 °F (135 °C) following each coat. Total film thickness of coating to be 0.9 mil.

In this designation, the symbols used represent:

M11 -- Mechanical Finish, As Fabricated, Specular (Table 2-3)

M4x -- Mechanical Finish, Non-Directional Textured, to be specified

C12 -- Chemical Finish, Non-etched Cleaned (Table 2-4)

O7x -- Coating, Clear Organic, Thermoset, to be specified.

TABLE 2-2 – SUMMARY OF STANDARD DESIGNATIONS FOR COPPER ALLOY FINISHES

In this listing, those finishes printed in **boldface type** are the ones most frequently used for general architectural work; those marked * are commonly used for hardware items.

MECHANICAL FINISHES (M)			
As Fabricated	Buffed	Directional Textured	Non-Directional Textured
M10 – Unspecified	M20 – Unspecified	M30 – Unspecified	M40 – Unspecified
M11 – Specular as fabricated	M21 – Smooth specular*	M31 – Fine satin*	M41 – (Unassigned)
M12 – Matte finish as fabricated	M22 – Specular*	M32 – Medium Satin	M42 – Fine matte*
M1x – Other (to be specified)	M2x – Other (to be specified)	M33 – Coarse satin	M43 – Medium matte
		M34 – Hand rubbed	M44 – Coarse matte
		M35 – Brushed	M45 – Fine shot blast
		M36 – Uniform	M46 – Medium shot blast
		M3x – Other (to be specified)	M47 – Coarse shot blast
			M4x – Other (to be specified)
CHEMICAL FINISHES (C)			
Non Etched Cleaned		Conversion Coatings	
C10 – Unspecified		C50 – Ammonium chloride	(patina)
C11 – Degreased		C51 – Cuprous chloride-hydrochloric acid	(patina)
C12 – Cleaned		C52 – Ammonium sulfate	(patina)
C1x – Other (to be specified)		C53 – Carbonate	(patina)
		C54 – Oxide	(statuary)
		C55 – Sulfide*	(statuary)
		C56 – Selenide	(statuary)
		C5x – Other (to be specified)	
COATINGS – CLEAR ORGANIC (O)			
Air Dry (Gen'l arch'l work)	Thermoset (Hardware)	Chemical Cure	
O60 – Unspecified	O70 – Unspecified	O80 – Unspecified	
O6x – Other (to be specified)	O7x – Other (to be specified)	O8x – Other (to be specified)	
COATINGS – LAMINATED (L)			
	L90 – Unspecified		
	L91 – Clear Polyvinyl Fluoride		
	L9x – Other (to be specified)		

COATINGS – VITREOUS and METALLIC

Since the use of these finishes in architectural work is rather infrequent, it is recommended that they be specified in full rather than being identified by number.

COATINGS – OILS AND WAXES

These applied coatings are primarily used for maintenance purposes on site. Because of the broad range of materials in common use, it is recommended that, where desired, such coatings be specified in full.

TABLE 2-3 – STANDARD DESIGNATIONS FOR MECHANICAL FINISHES

Type of Finish	Designation	Description	Examples of Method of Finishing
AS FABRICATED	M10	Unspecified	Optional with finisher.
	M11	Specular as fabricated	Cold rolling with polished steel rolls.
	M12	Matte finish as fabricated	Cold rolling followed by annealing; hot rolling, extruding, casting.
	M1x	Other	To be specified.
BUFFED	M20	Unspecified	Optional with finisher.
	M21	Smooth specular	Cutting with aluminum oxide or silicon carbide compounds, starting with relatively coarse grits and finishing with 320 grit, using peripheral wheel speed of 6,000 ft/min (30 m/s). Follow by buffing with aluminum oxide buffing compounds using peripheral wheel speed of 7,000 ft/min (36 m/s).
	M22	Specular	Cutting with compounds as for the M21 finish, followed by a final light buffing.
	M2x	Other	To be specified.
	M30	Unspecified	Optional with finisher.
DIRECTIONAL TEXTURED	M31	Fine satin	Wheel or belt polishing with aluminum oxide or silicon carbide abrasives of 240 - 320 grit, using a peripheral speed of 6,000 ft/min (30 m/s).
	M32	Medium satin	Wheel or belt polishing with aluminum oxide or silicon carbide abrasives of 180-240 grit, using a peripheral wheel speed of 6,000 ft/min (30 m/s).
	M33	Coarse satin	Wheel or belt polishing with aluminum oxide or silicon carbide abrasives of 120 - 180 grit, using a peripheral wheel speed of 6,000 ft/min (30 f/s).
	M34	Hand rubbed	Hand rubbing with #0 stainless steel wool and solvent, #0 pumice and solvent, non-woven abrasive mesh pad or Turkish oil and emery.
	M35	Brushed	Brushing with rotary stainless steel, brass or nickel silver wire wheel. Coarseness of finish controlled by diameter and speed of wheel and pressure exerted.
	M36	Uniform	Wheel or belt polishing in a single pass with aluminum oxide or silicon carbide abrasives of 60-80 grit, using a peripheral speed of 6,000 ft/min (30 m/s).
	M3x	Other	To be specified.
NON-DIRECTIONAL TEXTURED	M40	Unspecified	Optional with finisher.
	M41	(number unassigned)	
	M42	Fine matte	Air blast with #100-#200 mesh silica sand or aluminum oxide. Air pressure 30-90 psi (207-621 kPa). Gun 12 in. (305 mm) from work at an angle of 60-90 degrees.
	M43	Medium matte	Air blast with #40-#80 mesh silica sand or aluminum oxide. Air pressure 30-90 psi (207-621 kPa). Gun 12 in. (305 mm) from work at an angle of 60-90 degrees.
	M44	Coarse matte	Air blast with #20 mesh silica sand or aluminum oxide. Air pressure 30-90 psi (207-621 kPa). Gun 12 in. (305 mm) from work at an angle of 60-90 degrees.
	M45	Fine shot blast	Air blast with S-70 metal shot.
	M46	Medium shot blast	Air blast with S-230 metal shot.
	M47	Coarse shot blast	Air blast with S-550 metal shot.
	M4x	Other	To be specified.

TABLE 2-4 – STANDARD DESIGNATIONS FOR CHEMICAL FINISHES

Type of Finish	Designation	Description	Examples of Method of Finishing
NON-ETCHED CLEANED	C10	Unspecified	Optional with finisher.
	C11	Degreased	Treatment with organic solvent.
	C12	Chemically cleaned	Use of inhibited chemical cleaner
	C1x	Other	To be specified.
CONVERSION COATINGS	C50	Ammonium chloride (<i>patina</i>)	Saturated solution of commercial sal ammoniac, spray or brush applied. Repeated applications are required sometimes.
	C51	Cuprous chloride Hydrochloric Acid (<i>patina</i>)	In 500 ml. of warm water, dissolve 164 g. cuprous chloride crystals, 117 ml. hydrochloric acid, 69 ml. glacial acetic acid, 80g. ammonium chloride, 11 g. arsenic trioxide. Dilute to 1 liter. Apply by spray, brush, or stippling. Repeated applications are required sometimes. Avoid use of aluminum containers.
	C52	Ammonium Sulfate (<i>patina</i>)	Dissolve in 1 liter of warm water, 111 g. ammonium sulfate, 3.5 g. copper sulfate, 1.6 ml. concentrated ammonia. Spray apply. 6-8 applications can be required under high humidity conditions.
	C53	Carbonate (<i>patina</i>)	Various formulations utilizing copper carbonate as the major constituent.
	C54	Oxide (<i>statuary</i>)	Principal formulations utilize aqueous solutions of copper sulfates and copper nitrates at temperatures of from 85° C to boiling; or permanganate solutions at temperatures of from 80° C to boiling, using immersion periods of from 30 sec. to 5 min.
	C55	Sulfide (<i>statuary</i>)	2-10% aqueous solutions of ammonium sulfide, potassium sulfide, or sodium sulfide. Solutions swabbed or brushed on. Repeated application increases depth of color.
	C56	Selenide (<i>statuary</i>)	Principally proprietary formulations. Because the solutions are toxic, user preparation should be avoided. Follow manufacturer's directions for use without deviation.
	C5x	Other	To be specified.

TABLE 2-5 – STANDARD DESIGNATIONS FOR LAMINATED FINISHES

Type of Finish	Designation	Description	Examples of Method of Finishing
FILM LAMINATES	L90	Unspecified	Optional with finisher.
	L91	Polyvinyl Fluoride	A one mil clear film, adhesive bonded to the metal surface.
	L9x	Other	To be specified.

REFERENCES

For more detailed information on the subject of finishes for copper alloys, the following references can be contacted for their publications:

American Society for Metals (ASM International), 9639 Kinsman Road, Materials Park, OH 44073-0002; www.asm-intl.org.

Architectural Metals, L. William Zahner, John Wiley and Sons, New York, NY.

Builders Hardware Manufacturers Association (BHMA), 355 Lexington Avenue, 17th Floor, New York, NY 10017; www.buildershardware.com.

Copper Development Association, Inc. (CDA), 260 Madison Avenue, New York, NY 10016, www.copper.org.

Electroplating Engineering Handbook, Van Nostrand Reinhold Publishing Corp., New York, NY.

The Colouring, Bronzing, and Patination of Metals, Hughes and Rowe, Whitney Library of Design, New York, NY.

Internet Search Engine.

Chapter 3: Finishes for Stainless Steel

NAAMM/NOMMA AMP 500-06

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FINISHES FOR STAINLESS STEEL

General

The variety of finishes used on architectural stainless steel is almost infinite and includes standard mill and polished, proprietary, electropolished, blasted, rolled, textured, colored, etched, and any combination of these. The polished finishes are most popular, followed by the other finishes most of which are applied mechanically. The most common finishes are listed in the following summary.

Most of the stainless steel used in architectural work is supplied in the form of sheet or strip, however bar, plate, tube, pipe, wire, extruded and cast shapes and other common forms are available. Finishes for sheet, strip, and plate products are defined in ASTM A 480/ASTM A 480M, General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet, and Strip. There are no ASTM specifications covering finishes for other product forms but sheet finishes are often applied to them.

The most common finishes for stainless are sheet finishes. They are available from a mill, ser-

vice center, or polishing house directly, and are also commonly applied by product fabricators. Other finishes, such as embossing, coining, engine turning, non-directional, distressed, and special rolled finishes are also applied mechanically. Non-mechanical options include color and etching.

Mechanical Finishes

A) Standard Rolled Mill Finishes

Rolled finishes are created when a stainless steel coil is passed through a set of rolls. The finish on the rolls is transferred to the surface of the coil. This category includes the mill finishes No. 1, 2B, 2BA, 2D. They are directional and the rolling direction should be marked on the back of cut panels so they can be installed in the same direction. Alternatively, the metal can be ordered with protective strippable film with printed arrows indicating direction applied to the front. There can be differences in appearance from one end of the coil to the other due to roll wear. For maximum uniformity, panels are numbered as they are cut from

SUMMARY OF TYPICAL STAINLESS STEEL FINISHES

	Finish	Finish Normally Supplied By			Relative Costs (on flat surfaces)
		Mill	Proces- sor	Fabricator or Finisher	
MECHANICAL	Standard Mill Finishes	X			base
	(Nos. 1, 2D, & 2B sheet and Nos. 1 & 2 strip)				
	Bright Annealed	X			low
	Polished ¹				
	Nos. 3 & 4 sheet	X	X	X	low to medium
	Hairline	X	X	X	low to medium
	No. 6 sheet			X	high
	Nos. 7 & 8 sheet		X	X	medium
	No. 9 (Super No. 8) sheet		X	X	high
	Embossed and Coined	X	X		medium to high ²

The term *Finish Processor*, as used here, refers to a "middleman" between the mill and the fabricator, who applies coatings, textures, or other finishes to metal in bulk form, generally cut sheet or strip or coil stock. *Fabricator* refers to the producer of stock metal shapes or the manufacturer of the end use product. The fabricator also either provides the final finish or sends the fabricated product to a finisher who does this work. The *Custom Finisher* does not usually fabricate products, but applies finishes as specified to products fabricated by others.

The *Relative Costs* indicated are necessarily approximate, for general guidance only. Exact costs vary considerably with quantity, thickness of metal, type of product, quality of work, etc., and should always be verified.

¹ With the exception of hairline, No. 9, embossed and coined, these are ASTM A480 finishes. In addition there are numerous proprietary buffed, polished, and rolled finishes.

² Certain embossed patterns, because of their stiffening effect, permit the use of thinner metal, and this saving can in some cases offset their cost. In other cases patterned finishes involve extra cost.

the coil, and consecutive panels are installed in close proximity. If more than one coil is needed for a project, all of the coils should come from the same producer and off the same line.

1) Hot Rolled

The No. 1 finish is dull with uneven color and texture and is produced by hot rolling, annealing, and descaling by pickling. Grinding marks and similar blemishes are common. Heavy sheet, plate, bars, and shapes used for structural applications are supplied with this finish. When these components must be visible, it is common for a secondary finish, like polishing or abrasive blasting, to be applied to provide a uniform appearance. No. 1 finish is the least expensive mill finish.

2) Cold Rolled

Nos. 2D, 2B, and 2BA are sheet and strip finishes. They start with a cold rolled coil that is annealed and pickled.

The No. 2D finish is a uniform, dull, low reflectivity, sheet and strip finish. The dull appearance is produced by pickling or descaling. In architecture, this finish is almost exclusively used for roofing. A final pass through special dull rolls, which transfer their dull finish to the coil, is used to meet flatness requirements and improve finish uniformity. Very few service centers stock 2D, and it often must often be ordered in mill quantities. It is the preferred finish for deep drawing applications because the finish holds lubricants well.

The 2B finish is a more reflective and resembles a smooth, cloudy mirror. The final finish is produced by a light pass through polished rolls. Heavier passes can be used if higher tensile strengths are required (see ASTM A666) for structural applications. It can vary significantly in appearance from supplier to supplier and coil to coil ranging from a fairly dull finish that is only slightly brighter than a 2D to a fairly bright, cloudy mirror. It is rarely used for architectural applications other than flashings, but it is a common starting finish for polishing and embossing. There is no additional cost for applying either finish. Even if a secondary finish will be applied, finish matching is maximized by obtained all of the 2B from the same producer and processing line (sequential coils).

When the final annealing is done in a furnace with a controlled atmosphere, it is referred to as Bright Annealing. For architectural applications, the

bright annealed coil is given a light pass through highly polished rolls to flatten the coil and enhance finish uniformity. This finish is identified as 2BA. The process produces a bright, reflective, mirror-like finish, which is used as a lower cost alternative to highly polished stainless for architectural trim, panels, and fascia. The appearance of this mirror-like finish can vary from hazy to clear. Because it is less uniform than polished stainless, it is generally used above street level or for elevated interior applications. It is not unusual for a Buffed BA to be specified for aesthetic applications where consistency is important. Buffing produces a consistent mirror finish. BA can also be the starting finish for embossing or coining, selective polishing or etching. It is slightly more expensive than a No. 2D or No. 2B finish.

B) Coining and Embossing

Both *Coining* and *Embossing* are the result of passing a coil through a specially designed set of rolls to create a raised pattern. Pressing the pattern into the stainless steel displaces and cold works the metal resulting in an increase in strength. The pattern depth or degree of metal displacement determines the increase in strength and impact and scratch resistance. These finishes provide improved visual flatness and increase in strength. They also make it possible to use thinner sections which can sometimes offset the added cost of this finish. Each supplier has a wide range of unique patterns.

When a coil is passed through one smooth and one textured roll, it is referred to as Coining and the process creates a light, raised, one-sided pattern. The most popular Coined patterns mimic fabric-like lines. This finish has been used on the exterior of many well known stainless steel buildings to achieve optical flatness including the Petronas Towers and Canary Wharf.

Both *Embossing* rolls have pattern surfaces that interlock with each other. This creates the deep, two-sided pattern. Embossed and Coined patterns are used for applications like roofing, wall panels, column covers, furniture, elevator panels, kitchen refrigerator doors, cabinets, and back splashes.

The starting finishes are most often 2B or 2BA but occasionally a 2D or fine No. 4 is used. The choice of starting finish determines reflectivity. These stainless steel finishes are covered by ASTM A947M unless heavy gauge floor plate is desired. Stainless

steel floor plate is covered by ASTM A793.

C) Other Rolled Finishes

Rolled finishes were developed by stainless steel producers to mimic the appearance of common finishes. They simulate abrasive blasted and the No. 3, No. 4, and Hairline polished finishes. They are applied by passing the coils through specially treated rolls and are one- or two-sided. Their strength, impact, and scratch resistance are similar to that of other flat finishes but they are generally more uniform in appearance from coil to coil and provide better corrosion resistance. They have been used for roofing, wall panels, appliances, and other applications. The finishes that mimic abrasive blasting are flatter, more uniform, and more cost effective than abrasive blasted sheet or strip. The rolled finishes that simulate No. 3 or 4 finishes are approved alternatives to mechanically polished No. 3 and 4 finishes in ASTM A480/A480 M.

D) Other Mechanical Finishes

1) Angel Hair (Angel Hair and Suede are proprietary names. Vibration or non-directional are more generic terms.)

There are numerous names for this finish including vibration, non-directional polish, and suede finish. A very fine, non-directional scratch pattern is created with a stainless steel wire wheel or a vibrating nonmetallic abrasive pad. The scratches can be long or short, and the finish can be applied by hand or with CNC-operated equipment to flat and curved surfaces. It hides light random scratching in high traffic areas and has a soft, low reflectivity appearance. This finish has been used for both interior and exterior applications and has a fairly low level of reflectivity. Examples include the Experience Music Museum and Walt Disney Concert Hall. This finish is usually blendable.

2) Distressed Finishes

Distressed finishes have coarser scratches

than the Angel Hair finish and are applied using a small grinding wheel, coarse stainless steel wire brushes, or a coarse nonmetallic abrasive pad. They can be applied by hand or with CNC-operated equipment. This pattern hides heavier random scratching in high traffic areas. This finish is usually blendable.

3) Swirl Patterns

Grinding wheels or stainless steel wire brushes are used to create swirl patterns, which can range in size and pattern. The finish can be applied by hand or with CNC-operated equipment to flat or curved pieces and to small or large areas. Swirl patterns hide accidental scratches in high traffic areas and add visual depth. The pattern is sometimes described as having a 3 dimensional appearance. A well-known example of extensive use of this finish is the Denver Airport. This finish is usually blendable.

4) Engine-Turned Patterns

Engine-Turned patterns are created on cut pieces of sheet or strip with CNC-controlled equipment, which grind circles ranging from 0.5 in. (13 mm) to 12 in. (305 mm) in diameter into a highly polished or bright annealed finish. The circles can range in size, overlap, and form decorative patterns. When the ground circles cover the entire surface, they can be effective in making light random scratching less visible by drawing the eye to the ground circle.

5) Abrasive Blasted

Stainless steel can be abrasive blasted with a variety of media to create a non-directional, repairable finish. The choice of media will determine the appearance. It is important to clean the surface before and after blasting. Clean media that has not been used on other metals must be used to avoid surface contamination. Steel shot should never be used on stainless steel. Some abrasives, such as sand and aluminum oxide, can

Finish appearance with various abrasive media

Abrasive Media	Finish
fine sand or silicon carbide	dark, coarse finish
glass beads	light, smooth, grainy finish
stainless steel shot	small, curved indentations
ground quartz	shiny, coarse, angular indentations

become embedded in the surface and can lead to unanticipated corrosion problems in demanding applications. Abrasive blasting is ideal for heavier sections and improves scratch resistance by cold

working the surface. Distortion can occur when abrasive blasting thin flat sheets. Fingerprints are much less noticeable on more reflective abrasive blasted surfaces.

PRECAUTIONS

Protective Strippable Plastic Films

Protective strippable plastic films can be applied by the producer, processor, fabricator or finisher to protect the stainless steel surface finish during shipment, installation and fabrication. The use of a strippable protective plastic film, during forming operations that do not require heat, helps to protect the surface from contamination by other metals and light scratching. It also acts as a lubricant. During shipping, storage or installation, film can help to prevent damage from light scratching. Fine steel particles and dirt accumulations from the job site are generally removed with the film. If an appropriate film life is specified and the film is UV rated, the protective film can be left in place until just prior to turnover. This can eliminate the need for final cleaning or reduce the cleaning necessary.

The commonly used protective films are porous and do not prevent corrosion from salt water, water containing deicing salt, swimming pool atmospheres, corrosive acids and other substances that can be corrosive to some stainless steels. When there is exposure to a corrosive environment, the presence of a film can accelerate corrosion by acting as a crevice. Protective strippable films should be removed immediately after installation if the environment is corrosive.

If the component that the film is applied to will be stored or installed in an exterior location, a UV rated film must be specified. The specified film life should take into consideration the total time that the film will be required and potential project delays. If the film is nearing the end of its warranted life, it should be removed and replaced as required. Film that is left in place past its warranted life or exposed to conditions for which it was not designed can be difficult to remove, leave residual adhesive on the surface, or be a factor in corrosion.

When stainless steel arrives from the mill or processor, it has a protective passive film on the surface. As long as the surface is clean and exposed to oxygen, the passive film will automatically form if the surface is abraded or machined. If the surface is protected from contamination and scratching during fabrication, transit, and installation, and there is no welding, chemical passivation of the surface after fabrication is not required. Washing with a mild, chloride-free detergent and water solution or an ammonia and water window washing solution may still be necessary.

If an improper film type is selected or it is left in place too long, the film supplier should be contacted to determine an appropriate water based cleaner or solvent for removal of the residual adhesive. The type of adhesive determines the most effective cleaner. Solvents will not damage the stainless steel. If a solvent based cleaner is needed, rubbing alcohol or citric cleaners are often tried before more aggressive solvents.

The Use of Mechanical Finishes on Stainless Steel

For some architectural applications, the metal is ordered from the mill, service center or processor with the desired final finish. If proper care is exercised, such fabricating processes as brake forming, roll forming, punching, shearing, and welding

will likely affect the surface only locally and in a minor way; and these areas can be “blended” to match the adjacent areas **if they have a directional polished finish.**

The mill rolled, embossed, coined, and colored finishes **cannot be matched** in the fabricator’s shop. As a general rule, therefore, **these**

finishes should not be specified for products whose fabrication requires severe bending or welding of the metal unless subsequent overall finishing of the product is intended, or appearance is not critical.

Pre-polished mill finishes of 3 to 7 can vary from supplier to supplier and coil to coil. If the finishes are to match, all the material should be polished by one experienced metal finisher who can control the uniformity of the finish to a more precise degree.

For welded assemblies in which fusion welds must be finished to blend inconspicuously with adjacent metal, a directional finish such as No. 4 sheet finish or a special “blendable” finish is usually advisable.

The proper use of abrasives is very important - use silicon carbide, not aluminum oxide, for corrosive interior or exterior applications. Silicon carbide abrasives may need to be replaced more frequently to obtain a uniform appearance. Aluminum oxide can be used in interior, non-corrosive applications. A 36-50 grit aluminum oxide can produce a bright, uniform finish. Do not use sand, glass beads, or other abrasive media previously used on other metals.

Removing Embedded Iron or Carbon Steel

When iron or carbon steel particles adhere or become embedded in the surface, they will rust and discolor the stainless steel and give the incorrect impression that the stainless steel is rusting. Iron contamination can result from carbon steel wire brushing; inadequate cleaning of tools or work areas where carbon steel is also fabricated; forming without a protective strippable plastic film; use of contaminated abrasive blasting with media; improper handling; or exposure to airborne carbon steel particles in the shop or at the job site. Depending on the depth of penetration, the rusting or discoloration can be removed by passivation. ASTM A380 defines passivation and describes appropriate cleaning methods for removing iron or carbon steel contamination and approved nondestructive tests to determine if there is iron contamination.

If the stainless steel has been stained by carbon steel surface contact but the carbon steel is

not embedded in the surface, the staining can usually be removed with either phosphoric or oxalic acid followed by a water rinse. If the finish is not subject to damage from fine abrasives, a 200 mesh or finer calcium carbonate abrasive with no chlorides, such as Bon Ami, can be used. Two other household cleaning products, Zud and Bar Keeper's Friend, include both oxalic acid and this fine abrasive but they also contain chlorides so they must be carefully rinsed off surfaces. Abrasives should not be used on delicate finishes such as colored stainless steel or mirror finishes.

If iron is embedded in the surface, the depth to which it is embedded will determine the cleaning method. Cleaning with phosphoric acid, nitric acid, or citric acid/sodium nitrate solution followed by a water rinse can be used. Some suppliers of stainless steel welding products also sell affective stronger stainless steel rust removers.

The surface must be degreased prior to an acid treatment and the acid thoroughly rinsed off and neutralized after use. With proper application, these acids will aggressively attack and remove carbon steel but will not harm the stainless steel surface. Deeply embedded iron particles can necessitate significant surface removal with a coarse abrasive, grinding wheel or belt followed by refinishing. Alternatively, deeply embedded carbon steel can be removed by painting the problem area with stainless steel pickling paste per manufacturers recommendations. This strong acid will remove even deeply embedded carbon steel but refinishing will be necessary. The acid must be neutralized after use.

Weld Clean-Up

Weld scale and heat tint must be removed in accordance with ASTM A380 to restore the corrosion resistance and appearance of the stainless steel.

Weld heat tint and weld splatter can be removed effectively with mechanical cleaning or a stainless steel pickling paste. Acceptable mechanical cleaning methods include use of a clean stainless steel wire brush or a grinding wheel. In particularly corrosive environments, research has shown that a combination of pickling paste and grinding is the most effective means of maximizing the weld's corrosion resistance. No matter which method is used, the chromium depleted surface layer must be removed to restore corrosion resis-

tance. A visual standard should be considered to establish aesthetic requirements.

Oil-Canning Avoidance

To minimize “oil-canning” in large flat areas, a nonreflective matte, textured, patterned, or contoured finish is often recommended. Highly polished reflective finishes should be used in such locations only if extreme care is given to thickness selection, detail design, and fabrication. These surfaces are also susceptible to scratches and dents if used at pedestrian level and can look oil canned even when they are very flat.

Post Installation Cleaning

All foreign matter should be thoroughly cleaned from stainless steel surfaces following installation to restore the original appearance. This is typically done with a mild detergent and water solution, ammonia and water window washing solution or pressure washing with hot water. Cleaning guidelines can be obtained from the Nickel Development Institute’s Guidelines for Maintenance and Cleaning, series 11 014, or ASTM A380 can be referenced.

In new construction, many contractors use a muriatic acid (also known as hydrochloric acid) solution to clean new masonry, tile, stone, or cement work. Muriatic acid will aggressively attack any stainless steel causing rapid severe corrosion. If it splashes or sprays on to stainless steel it must be thoroughly washed off and neutralized immediately to prevent corrosion.

Surrounding surfaces should also be neutralized, so that residual acid residue does not combine with moisture and come in contact with the stainless steel at a later date. Citric acid masonry cleaning products will not damage stainless steel but the solution should be confirmed to be free of muriatic acid.

Polished Finishes

These finishes are produced by successively finer polishing belts or by passing a stainless steel coil through special rolls that simulate a No. 3 or 4 polish. The No. 7, 8 or 9 finishes are polished with successively finer belts and then buffed. They vary in cost depending on the number of operations involved and the degree of smoothness required. (see Table 3-2) They can be provided on

sheet, strip, tube, pipe, and any of the other stainless steel shapes.

The Nos. 3 and 4 polished finishes are characterized by very fine parallel “grit lines,” and are produced by belt or wheel polishing with fine grit abrasives or by rolling. When it is mechanically finished, No. 3 is usually finished with abrasives between 80 and 150 grit and on sheet or strip it can typically have an average surface roughness of up to Ra 40 micro-inches. A No. 4 is commonly used as an architectural finish and can be produced by mechanical polishing or rolling. If mechanical polishing is used, the final pass can be between 120 and 320 grit. The average surface roughness on sheet or strip can typically be up to Ra 25 micro-inches. No common stainless steel specification requires that a finish meet specific surface roughness requirements. Surface roughness influences appearance and corrosion performance so it can be important to specify a maximum allowable surface roughness or surface roughness range. There can be overlap between the surface roughness measurements and grit ranges for the No. 3 and No. 4 finishes. Either finish can be polished wet or dry. Wet polishing produces a smoother, finer finish. When they are applied to sheet, the polishing lines are usually short, but on pipe, tube, and fabricated components the polishing lines are often long. This should be considered when matching finishes. Polished finishes on tubing and pipe are described by the grit rather than a finish number.

Fabricators or specialty polishers normally apply polished finishes to stainless steel bars and shapes. Small cross section flat round, hex and square bars are available “cold finished.” Heavier sectioned flats, angles, other shapes are commercially available only “hot rolled” or “extruded”. They are typically purchased with a rough abrasive blasted and pickled surface that must be ground smooth before polishing. Polishing such shapes is more expensive. Thinner angles, channels and shapes can be cold rolled after polishing. If this is done with a protective strippable plastic film in place that is suitable for forming, no further polishing is required.

A soft, satin, directional No. 6 Finish is typically produced by Tampico brushing a No. 4 finish with an oil and abrasive mixture. It has a silver white appearance. The high wear rate of Tampico brushes make it difficult to obtain a uniform appearance and this finish is known for having fingerprint problems. ASTM A480/A480M allows other polishing

methods to be substituted if they produce a finish with the same surface roughness, reflectivity, and an appearance that a stainless steel surface finish expert considers visually identical. Polishing lines should be soft, and the resultant finish should be much less reflective than a No. 4. The No. 6 polish is not widely available. It was used for the exterior columnar features on the exterior walls of the Empire State Building and in other early stainless steel projects. A surface finish sample that acts as a visual standard is particularly important when specifying this finish because a wide range of visually different finishes are sometimes called a No. 6.

Still smoother and more reflective finishes (Nos. 7 and 8 Sheet Finishes) are obtained by buffing polished surfaces. The semi-bright No. 7 is produced by buffing a finely ground finish. No. 7 is a mirror-like finish but residual grit lines are still visible. The highly reflective, mirror-like, No. 8 is typically produced by polishing with successively finer abrasives, then buffing. Very faint polishing grit lines can be visible on the final product.

Additional Polished Finishes

A) Hairline Polish

A finish with very long seemingly endless polishing lines is called a hairline, long-grain, or fine-line finish. It is more reflective than a No. 4 polish. Small scratches can be repaired in the field with Scotch-Brite® pads of equivalent grit or roughness. Some suppliers have identified this as a No. 5 or No. 6 finish, but this finish is not defined by ASTM A480/A480M. A visual standard that is agreed upon in advance by all parties is advisable. This finish can be produced by applying it over a bright annealed finish, passing a bright annealed coil through special rolls, or as the final step in a series of gradually finer abrasives. If this finish is obtained by polishing, it is applied with Scotch-Brite® pads.

B) No. 9 or Super No. 8 polish

This finish is referred to as a Super or Supreme No. 8 or No. 9, 10, 11 or even 12 polish. It is buffed longer than an ASTM No. 8 polish, typically about 60 minutes, to achieve a true mirror polish. It is not defined by ASTM and supplier terminology for this finish varies. Applications range from decorative panels to bathroom mirrors. It is usually purchased already machine polished in sheet form and requires specifying stainless steel with

very low sulfur (0.005 or less) levels. If the right quality of stainless steel is not specified, impurities in the metal can cause flaws during polishing. A true mirror finish obtained by hand polishing is expensive.

Colored Finishes

Stainless steel can be colored by several methods. The scratch resistance and color stability of these processes vary and should be taken into consideration during selection. Although some of these processes slightly improve corrosion resistance, this should not be considered a substitute for selecting an appropriate grade of stainless steel for the environment. Any welding must be done before the color is applied. The only coloring process that is repairable is paint.

Electrochemical coloring (also called light interference or INCO coloring) is achieved by immersing stainless steel in a hot acid solution and applying an electrical current. A full spectrum of colors is available including gold, bronze, purple, blue, red, black, and green. Color can be applied uniformly or varied for a rainbow effect. Ultraviolet radiation does not cause fading. The underlying finish is visible. Color can be removed selectively by etching, polishing, or engraving. Scratching can damage the color. When the color is applied over a coined or embossed finish and the raised areas are buffed, the remaining color is recessed and protected and this finish has performed well in high traffic areas. Forming or bending sharp angles can change the finish color in the deformed area. Flat panels can appear to be different colors when viewed from different angles or under different light conditions. Curving can introduce visible color variation on large sheets. Some colors are more difficult to match from sheet to sheet and requirements should be discussed with suppliers in advance. The process slightly improves corrosion resistance but not significantly enough to change stainless steel grade or type requirements.

Sputtering is sometimes referred to as plasma vapor deposition (PVD) and applies a very thin, colored ceramic coating to the surface. Available colors include gold, black, blue, wine red, rose gold, silver gold, and brass. The most common color is gold, which has a TiN (titanium nitride) coating and is sometimes referred to as Ti-Gold. The color is stable, uniform, and significantly more abrasion resistant than electrochemical coloring.

The pattern of underlying finish is visible and color can be removed selectively by etching or engraving. The finish can be damaged by more aggressive scratching but it is significantly more scratch resistant than electrochemical color. If the surface is not properly prepared prior to sputtering, delamination can occur during bending. Purchase requirements should require that the material pass a bend test prior to shipment acceptance.

A dull black color can be achieved by immersing stainless steel in a molten salt bath of sodium dichromate. The color can be brightened with wax or oil. The color is durable, reasonably abrasion resistant, and does not chip or fade. Moderate deformation does not damage the color. The automotive industry and manufacturers of solar collectors use this coloring method. It is rarely used for architecture.

Painting stainless steel is similar to painting other metals except that it is done for aesthetic reasons rather than corrosion protection. The repainting schedule will be dependent on the paint's performance. The surface finish must be clean, dry, and rough enough for adherence. An appropriate primer and paint system should be selected. The No. 2B and No. 2D mill finishes, etched finishes, and a No. 3 and 4 polishes have been painted successfully. Several suppliers sell pre-painted or coil coated stainless steel.

Terne metal (80% lead, 20% tin), tin, and a zinc/tin coatings are primarily used for roofing but have also been used for exterior wall panels. They weather to a medium to dark gray and can be damaged by scratching or abrasion. The final color is dependent on the environment. Traditional lead containing coatings should not be used in locations with low sulfur dioxide levels in the air or the lead can oxidize resulting in red spots on the surface.

The coating provides some additional corrosion protection but it should not be assumed that a less corrosion resistant stainless steel can be used. This finish can be painted using manufacturer recommended primers and paints.

Stainless steel can be plated with gold, copper alloys, and other metals. Copper plated stainless has had limited use in roofing applications when the strength of stainless and color of copper were desired. Gold plating is soft and easily abraded and is sometimes hard coated. The hard coating could discolor and deteriorate over time.

Electropolished Finishes

Electropolishing can be used on stainless steel, especially austenitics. This process, described under Bright Finishes in Chapter 1 Finishes for Aluminum, is used for floor plate and items that would be difficult to polish, such as hardware and trim. Electropolishing reduces surface roughness, removes inclusions, and increases reflectivity. Smoother finishes are more corrosion resistant. In addition, the process produces a higher quality protective passive surface layer on stainless steel more than what would naturally occur in air and, in combination with the surface smoothing and removal of inclusions, improves corrosion resistance. Electropolishing is a good way to reduce the potential for corrosion in corrosive exterior and interior applications like pools or shower rooms, but it should not be considered a substitute for using an appropriate grade for that environment.

Graphic Finishes

Graphic etched, polished and abrasive blasted patterns are created by selectively applying a protective acid resistant film to a highly polished surface. Etching uses acid to remove a thin layer of stainless steel from the unprotected areas and changes the color of these areas to dull silver gray and roughens the surface. The etched pattern can be left as is or made more reflective. The finish is often electropolished after completion. Both custom and stock etched patterns are available.

In selective polishing, unprotected areas are polished or buffed to create a pattern. Some have a three dimensional appearance. In selective abrasive blasting, abrasive media are used to create the pattern. Fine detail can be achieved with any of these techniques, and the difference in reflectivity of the finishes creates the pattern.

Like other metals, letters or lines can be cut into stainless steel by engraving. This is most commonly used for signage. Engraved patterns can be electrochemically colored or sputtered and engraving can be done after both of these coloring processes.

Standard Product Dimensions

The standard dimensions for stainless steel sheet, strip, and plate are defined by ASTM A 480/A 480M General Requirements for Flat-Rolled Stainless and Heat-Resisting Steel Plate, Sheet,

TABLE 3-1 – CLASSIFICATION OF STAINLESS STEEL SHAPES

		Dimensions		
Item	Description	Thickness	Width	Dia. or size
PLATES	Flat-rolled or forged	3/16 (5) & over	over 10 (254)	
SHEET	Coils and cut lengths:	under 3/16 (5)	24 (610) & over	
STRIP	Coils and cut lengths:			
	Cold finished	under 3/16 (5)	under 24 (610)	
BARS	Hot finished flats	0.125 (3) & over	10 (254) or less	
	Cold finished flats	0.125 (3) & over	10 (254) or less	
PIPE and TUBING	The most commonly used ASTM specification for architectural and structural applications is ASTM A554 Standard Specification for Welded Stainless Steel Mechanical Tubing (round, square and rectangular). For information on standard sizes consult service centers, producers, or the Specialty Steel Industry of North America (SSINA) website. The SSINA website also lists producers and service centers.			
EXTRUSIONS and ROLL FORMED SHAPES	Structural components are often produced by extrusion and roll forming. The relevant specifications are ASTM A276 and A484/A484M. Some standard shapes are available but most are custom. Extrusions are limited in size to shapes that will fit inside a 9½ in. (229 mm) diameter circle Stainless steel that is up to 0.38 inches thick and 48 inches wide can be roll formed. A list of commonly stocked sizes and suppliers can be found at the Specialty Steel Industry of North America website.			
a)	ASTM A276 and A484/A484M are the specifications that cover stainless steel bars and shapes used in architecture.			
b)	General requirements for stainless steel wire and wire rods are covered in ASTM A555/A555M.			
c)	SSINA website is www.ssina.com .			

and Strip. ASTM does not provide surface finish definitions for other product forms. (ASTM does have dimensional tolerance requirements for other product forms.) The standard shapes and their dimensions are listed in Table 3-1. In the discussion that follows, the finishes for each type of product are explained.

Plate Finishes

Plate finishes are defined in ASTM A 480/A 480M. In most cases, plate is used for structural applications, but there are other installations where these finishes are used.

Hot-Rolled or Cold-Rolled, and Annealed or Heat Treated: The scale is not removed from the plate. This impairs corrosion resistance making the finish unsuitable for most applications. It is usually an intermediary processing step or used for heat resisting applications.

Hot-Rolled or Cold-Rolled, and Annealed or Heat Treated, and Abrasive Blasted or Pickled: This dull silver finish is essentially equivalent to a No. 1 sheet finish and could be used for structural components. The surface is often not that uniform in appearance. Grinding marks and other surface imperfections are common so additional finishing after fabrication is typically assumed in aesthetic applications.

Hot-Rolled or Cold-Rolled, and Annealed or Heat Treated, Surface Cleaned and Polished:

This is generally equivalent to a No. 3 or 4 polish depending on the purchasers finish requirements. The surface is cleaned by abrasive blasted and pickling and polishing is used to smooth the finish and make it more uniform. This finish was used on the exterior of the Gateway Arch in St. Louis. There are polishing houses who specialize in plate.

Hot-Rolled or Cold-Rolled, and Annealed or Heat Treated, Descaled and Temper Passed: Passing the abrasive blasted and pickled plate through smooth rolls gives it a smoother finish.

Hot-Rolled or Cold-Rolled, and Annealed or Heat treated, Descaled; and Cold-Rolled and Annealed or Heat Treated, Descaled, and Optionally Temper Passed: Like the preceding finish this is smooth but with fewer surface imperfections.

Sheet Finishes

Sheet finishes are defined in ASTM A 480/A 480M. The stainless steel finishes most widely used in architectural work are sheet finishes. These are identified by a system of numbers and letters, the unpolished, or, “mill” finishes being Nos. 1, 2D, bright annealed (usually 2BA), and 2B, and the polished finishes being Nos. 3, 4, 6,

7, and 8. The use of the polished finishes is not limited to sheet products; they can be applied to all product forms if desired by referencing ASTM A480/A480M.

The sheet finishes are described broadly by the finishing operations used to obtain them, as shown in Table 3-2.

**TABLE 3-2 - DESIGNATION AND DEFINITION OF STANDARD
MECHANICAL FINISHES FOR STAINLESS STEEL SHEET IN ACCORDANCE
WITH Note 4, ASTM A480/A480M**

Finish Designation	Definition
Unpolished Finishes:	
No. 1	Hot-rolled, annealed and descaled - Commonly referred to as hot-rolled, annealed and pickled or descaled. This is a dull, nonreflective finish.
No. 2D	Cold-rolled, dull finish - A smooth, nonreflective cold-rolled, annealed, and pickled or descaled finish. This nondirectional finish is favorable for retention of lubricants in deep drawing applications.
No. 2B	Cold-rolled, bright finish - A smooth, moderately reflective cold-rolled annealed and pickled or descaled finish typically produced by imparting a final light cold-rolled pass using polished rolls. This general-purpose finish is more readily polished than a No. 1 or 2D finishes. Product with 2B finish is normally supplied in the annealed plus lightly cold rolled condition unless a tensile-rolled product is specified.
Bright Annealed	A bright, cold-rolled finish retained by final annealing in a controlled atmosphere furnace - A smooth, bright, reflective finish typically produced by cold rolling followed by annealing in a protective atmosphere so as to prevent oxidation and scaling during annealing.
Polished Finishes	
No. 3	Intermediate polished finish, one or both sides - A linearly textured finish that may be produced by either mechanical polishing or rolling. Average surface roughness (Ra) can generally be up to 40 micro-inches. A skilled operator can generally blend this finish. Surface roughness measurements differ with different instruments, laboratories, and operators. There can also be overlap in measurements of surface roughness for both No. 3 and No. 4 finishes.
No. 4	General purpose polished finish, one or both sides - A linearly textured finish that is produced by either mechanical polishing or rolling. Average surface roughness (Ra) can generally be up to 25 micro-inches. A skilled operator can generally blend this finish. Surface roughness measurements differ with different instruments, laboratories, and operators. There can also be overlap in measurements of surface roughness for both No. 3 and No. 4 finishes.
No. 6	Dull, satin finish, Tampico brushed, one or both sides - This finish has a soft, satin appearance typically produced by Tampico brushing a No. 4 finish.

No. 7	High luster finish - Has a high degree of reflectivity. It is produced by buffing a finely ground surface, but the grit lines are not removed. It is chiefly used for architectural or ornamental purposes.
No. 8	Mirror finish - This is a highly reflective, smooth finish typically produced by polishing with successively finer grit abrasives, then buffing. Typically, very faint buff of polish lines can still be visible on the final product. Blending after part assembly can be done with buffing.
TR Finish	Cold-worked to obtain specified properties - The finish resulting from the cold-rolling of an annealed and descaled or bright annealed product to obtain mechanical properties higher than that of the annealed condition. Appearance will vary depending upon the starting finish, amount of cold work, and the alloy.
Architectural Finishes	Sometimes described as a No. 5 finish – These are a separate category and may be negotiated between buyer and seller, as there are many techniques and finish variations available throughout the world.

Text notes in ASTM specifications: These notes are descriptive information and are not legally binding. If surface roughness maximums or specific surface appearance characteristics are desired the purchaser is encouraged to tighten the specification by making them an additional requirement.

Strip

Stainless steel strip has five mill finishes defined by ASTM A480/A480M. No.1 Strip Finish is similar to a No. 2D sheet finish, which is produced by cold rolling to the specified thickness, followed by annealing and pickling.

It varies in appearance from dull gray matte to a fairly reflective surface. No. 2 Strip Finish is the same as a No. 1 finish except that it is followed by a final cold roll pass, generally on highly polished rolls. If the rolls are highly polished, it is equivalent to a No. 2B sheet finish.

It is a smoother, more reflective finish than No. 1 Strip Finish. The Bright Annealed, TR Finish, and No. 3 and 4 polished finishes are also available on strip and are produced to the requirements for sheet finishes.

It should be recognized that within each of these finish categories some variation should be expected, due to the characteristics of the different alloys and differences in metal thickness and methods of processing.

Bars

Hot-finished bars are commonly produced by

hot rolling, forging, pressing, extruding, or similar hot working procedures applied to ingots, blooms, or billets. The bar may be heat treated and cleaned by blasting, pickling, or some other descaling method. Final finishes also include rough turning; and machine straightening, centerless grinding, and polishing. The dimensional tolerances for hot-finished bars are less stringent than those for cold-finished bars.

Bars cut from flat-rolled stainless steel products have two surfaces that are pickled or descaled, and two cut surfaces, except when the bar is heat treated subsequent to cutting, in which case all surfaces are descaled or pickled. The flat product can be polished prior to cutting, and the cut edges ground.

Cold-finished bars have the surface finish that results from hot-finished bars being further processed by additional cold drawing. The final finish can be cold-drawn, burnished, centerless ground, or polished to provide closer tolerances and improved surface finish. The dimensional tolerances applicable to cold-finished bars are more stringent than those applicable to hot-finished bars.

The optional surface conditions and finishes which can be specified for stainless bars are shown

in Table 3-3. Note that the mechanically polished finishes can be any of those identified as sheet finishes in Table 3-2 and should be specified by referencing ASTM A480/A480M and the specific finish.

Wire

Stainless steel wire is produced in a large variety of compositions and finishes, usually designed for certain specific end uses. Many of these are suitable for architectural uses, but, since ASTM A555/A555M does not define wire finishes, wire producers should be consulted for information.

Pipe and Tubing

Ornamental/Structural grade tubing and pipe (round, square, and rectangular) is usually produced from a No. 2 strip finished material in thicknesses less than 0.180 in. (5 mm) which is formed and seam welded. Thicknesses of 0.180 in. (5 mm) and up are usually produced from 2D annealed and pickled as well as hot finished raw materials. Specifying seamless tubing provides no additional corrosion benefit in architectural applications but can substantially increase cost. The relevant ASTM specification is ASTM A554.

Although these products are produced from strip or plate finishes, processing changes the surface finish on the end product. Stretch or tooling marks can be evident especially on larger OD and/or heavy wall material that has not been

polished. The surface can be polished by the mill supplier, a specialty polishing house, or the fabricator to equate to polished sheet finishes with the hot rolled product requiring a bit of extra effort. Round products requested pre-polished are supplied with either a circumferential or longitudinal finish. Square and rectangular tubing is supplied polished longitudinally.

If a finish similar to the sheet No. 3 or 4 polish is desired, final polishing grits of 180, 240 and 320 are available. These are generally longer grained finishes than sheet or strip finishes. Buffed finishes, which are similar in appearance to a No. 7 or 8 polish, are also available. It is generally more cost effective to purchase pre-finished product and blend the finish as necessary after fabrication. Large diameter square and rectangular tubing is typically not supplied by the mill suppliers with the corner radius polished. Due to the diversity of products, service centers or mill suppliers should be consulted regarding available finishes and surface conditions of each product.

Extrusions

The natural finish resulting from extrusion (usually followed by a drawing operation) resembles a No. 1 sheet finish. The surfaces can be finished by clean, unused sand or glass bead blasting or can be polished by the fabricator or finisher to produce a polished sheet finish if desired.

TABLE 3-3 – SURFACE FINISHES AND CONDITIONS FOR STAINLESS STEEL BARS

Surface Finishes	Condition		
	Hot worked only	Annealed or otherwise heat treated	Annealed and cold worked to high tensile strength*
Scale not removed (excluding spot conditioning)	X	X	
Rough turned	X	X	
Pickled or blast cleaned and pickled	X	X	
Cold drawn or cold-rolled		X	X
Centerless ground		X	X
Mechanically polished (sheet finishes)		X	X

* Produced in a variety of stainless steels including Types 303Se, 304/304L, and 316/316L, 430 and 17-4pH

TABLE 3-4 – FINISHES FOR STAINLESS STEEL HARDWARE

Code No.	Description	Nearest US Equivalent
629	Bright Stainless Steel, 300 Series	US32
630	Satin Stainless Steel, 300 Series	US32D

Hardware Finish Designations

Finishes for architectural hardware made of stainless steel are generally designated by finish code numbers of the Builders Hardware Manufacturers Association (BHMA). Listed below are the two most commonly used. Since U.S. Finish Designations occasionally appear in specifications, the nearest former U.S. equivalent of the BHMA number is shown on the list. For a complete listing and description of hardware finishes refer to ANSI/BHMA A156.18, American National Standard for Materials and Finishes.

Selection of Proper Grade, Care, and Maintenance of Stainless Steel

Stainless Steel came into being in the early 1900's. Metallurgical engineers discovered that adding chromium and nickel to ordinary carbon steel would improve stain and corrosion resistance. Stainless steels contain at least 12 percent chromium and form a thin (invisible), protective, corrosion-resistant, passive film on their surface. This film forms spontaneously as long as the stainless steel surface is clean when the chromium reacts with oxygen in air or water. If the film is damaged or removed during fabrication or polishing, it self-repairs immediately so long as the surface is clean.

The most commonly used architectural stainless steels are Types 304 and 316. The former is suitable for most interior and mildly corrosive exterior applications, but if the site is more aggressive, molybdenum-containing Type 316 or an even more corrosion-resistant stainless steel may be necessary to avoid corrosion, particularly if there will not be regular cleaning.

While it is assumed other architectural metals will corrode without preventive maintenance, stainless steel is often expected to remain pristine with little or no maintenance. The level of maintenance required to keep the material attractive in any given environment is determined by the stainless steel grade, finish, location, design, and owner's aesthetic requirements.

Rural or suburban areas with low population densities and light, non-polluting industry can be categorized as rural. A site that appears rural can be impacted by migrant air pollution, so it is important to determine if there is industry upwind of the site. Type 304/304L is usually the most cost-effective choice

for boldly exposed surfaces in rural areas. Sheltered surfaces could experience minor discoloration over time if not cleaned. Smoother surface finishes provide better resistance to tarnishing and accumulate less dirt. Regular washing helps to retain a pristine appearance.

Urban sites include residential, commercial, and light industrial locations with low to moderate pollution from vehicular traffic and similar sources. Type 304/304L is usually the most cost-effective choice unless pollution levels are high, in which case slight tarnishing can occur. This can be avoided with regular cleaning and by specifying smoother surface finishes. Type 316/316L performs well in areas with high levels of urban pollution, and while cleaning may not be necessary for corrosion resistance, it improves overall appearance.

Sulfur and nitrogen oxides from coal combustion, and gases released from chemical and process industry plants typically characterize industrial sites. Surface deposits, such as soot from incompletely burned fuel or iron oxides, increase the environment's severity.

When industrial pollution levels are low to moderate, Type 316/316L performs well and is usually the most cost-effective choice. Type 304/304L may be satisfactory if a smooth finish is selected for a regularly washed application. If pollution levels are high, Type 316 can develop corrosion staining, but this is minimized if smooth finishes and regular washing are specified. For aggressive conditions, a more highly alloyed stainless steel may be needed. Pollution controls have made aggressive conditions less common in the US but they are common in other parts of the world.

Seawater contains a mixture of salts (sodium, magnesium, calcium, and potassium chlorides), and local wind patterns determine how far they are carried inland. Generally, locations within 5 mi to 10 mi (9 km to 18 km) of salt water are at risk for chloride-related corrosion, but local weather patterns vary and the performance of metals near the site should be evaluated prior to material selection. Type 304/304L can experience severe pitting in coastal and marine environments and should be used with caution. If the environment is less corrosive, Type 304 is acceptable if a smooth surface finish is specified, and it is frequently cleaned. Type 316/316L is usually the most cost-effective stainless steel for low to moderately corrosive

coastal architectural applications, and generally provides good service. If unwashed, some discoloration can occur after long-term exposure.

A specialist should be consulted if the component is close to, or immersed in seawater to determine the most cost-effective grade. If the component is occasionally splashed, such as railings beside the water, Type 316 may be inadequate unless a smooth finish is used, and it is frequently washed. If a rougher finish is desired or regular cleaning is impractical, a more corrosion-resistant grade should be used, such as 317LMN, 904L, or 2205. If the material will be regularly splashed or immersed in seawater, super-duplex stainless steels, such as 2507 or six percent-molybdenum austenitic, should be specified.

Typically, chloride or salt accumulations on handrails, doorstops, and other street-level applications are heavier in areas where deicing products are used than in coastal locations. All deicing products contain chlorides, typically sodium, calcium or magnesium chloride. If a site is exposed to both coastal and deicing salt or chlorides, the environment becomes even more aggressive. Deicing salt carried by road mist and wind have been found as high as the 50th floor of high-rise buildings and over 600 ft (183 m) from busy highways. It contaminates soil and is found in airborne dust throughout the year. Vehicle and wind speeds and traffic levels are the most important factors in determining how far deicing salt laden road mists will travel.

If a location has low to moderate deicing salt exposure, is boldly exposed and washed by heavy rain in the spring, Type 316 needs only occasional cleaning to remove dirt accumulations, particularly if a smooth finish is selected. Some light staining can occur over time but can be removed.

If the application is in close proximity to a road or sidewalk, or if there are horizontal or sheltered surfaces, Type 316 is usually still suitable if a smooth surface finish is selected and if salt deposits are washed off annually after the last deicing. In some areas, heavy spring rain may provide sufficient cleaning. If a rough finish is selected or if cleaning is infrequent, staining can occur over time but can generally be removed. A more highly alloyed stainless steel may be needed in particularly aggressive environments with high salt and pollution exposure.

Research has shown a direct correlation be-

tween surface finish roughness and the likelihood of corrosion. Smoother surface finishes retain less dirt and debris, and provide better corrosion performance than rougher finishes. As a result of this research, the European Standard EN 10088 recommends a surface roughness of Ra 20 micro-inches or 0.5 microns or less for polished finishes used in environments with high levels of particulates, corrosive pollution, and/or salt exposure, and in applications where regular maintenance is unlikely. Alternatively, a more corrosion-resistant product could be used if a rough finish is desired for aesthetic reasons. Similar guidelines should be followed for finishes produced by means other than polishing. For most embossed finishes, the roughness of the finish should be measured prior to pressing the pattern into the metal. However, when the coined or embossed finish simulates another finish (i.e., abrasive blasting or polishing) or if the pattern is likely to retain dirt and debris, the roughness of the final finish should also be measured.

If the design requires welding sections thicker than about 0.25 in. (6 mm), and the weld will be exposed to a corrosive environment, use low carbon versions of the stainless steels (i.e., 304L or 316L) to reduce the risk of sensitization and improve weld corrosion resistance. (The corrosion resistance of Type 304 is equivalent to Type 304L, and Type 316 is equivalent to Type 316L.)

Stainless Steel Selection Guidelines Based on Site Score

Extracted from the International Molybdenum Association (IMOA) publication IMOA ABC 00, *"Which Stainless Steel Should I Specify for Exterior Applications?"*

Select all of the items on the following list that describe the site, design and maintenance schedule. Add up the points and calculate the total site score. Selecting smooth surface finishes, regular manual cleaning or heavy rain-washing, and avoiding sheltered components will reduce the potential corrosiveness of an environment. Surface roughness should be below Ra 20 micro-inches (0.5 microns or micrometers) and polished finishes should have a clean-cut silicon carbide finish. Information about the stainless steel selection system, case studies, and a free software program that assists users in making stainless steel selection decisions can be found at <http://www.imoa.info>.

Maintenance and Cleaning

If an appropriate stainless steel, finish, and design are selected, and there is adequate heavy rainfall to remove surface accumulations, it is possible for an application to look attractive for many years without regular manual cleaning. For a pristine appearance, only occasional cleaning is necessary to remove stubborn dirt and hydrocarbons.

Accumulations of corrosive airborne pollutants and salt can cause corrosion. Dirt accumulations can cause unsightly streaking. Where horizontal surfaces cannot be avoided, as in window sills and copings, the surfaces should be smooth, sloped for easy drainage, and provided with a projecting drip so that the wash does not run down the face of the wall below.

Joints in the wall should be so designed so that any water which penetrates them, as well as any condensation which can occur within the wall, will be conducted away by an internal drainage system.

When cleaning is required, a mild chloride-free detergent, water, and degreaser solution is usually sufficient. Alternatively, an ammonia and water window cleaning solution is an effective way of removing light soil and fingerprints. Stronger degreasers are needed for heavier oil and grease deposits. Proprietary stainless steel cleaners that do not contain oil, hydrocarbons, wax, or other products that coat the surface can also be used. Stainless steel panels can be washed when nearby windows are washed using the same cleaning solution.

In cases of stubborn dirt or staining, a chloride-free, 200-mesh or finer calcium carbonate powder, such as Bon Ami, can be used without damaging most finishes. Fine abrasive cleaners containing oxalic acid (such as Zud or Bar Keeper's Friend) are particularly effective against corrosion staining. Cleaners with abrasives are not appropriate for colored and other delicate finishes. Some household and 'stainless steel' cleaners

contain harsh abrasives and acids that will damage architectural finishes, and should be tested in an inconspicuous location before use.

Abrasive pads and cleaners should be avoided, as they will change the finish. Steel wool should never be used on stainless steel because steel particles will embed in the surface and cause staining of the stainless steel as the transferred material rusts. Soft non-metallic brushes that will not scratch the surface can be used to loosen dirt. If changing the surface finish is not a concern, stainless steel wool or a non-metallic abrasive pad (such as a Scotch-Brite® pad) can be used to remove stubborn stains.

The fabrication department can also contribute to ultimately rusting in spots. Many fabricators utilize work tables made of carbon steel and/or fabricate carbon steel using the same tools and while the job is being processed, the job can also be dragged across these work tables or cross contaminated by improperly cleaned tooling. This can embed carbon steel particles in the surface. These particles will contaminate the stainless and will eventually create a rusting problem in those contacted areas.

Temporary protective coatings of wax, oil, or lacquer are unnecessary; can accelerate corrosion as they fail; and are not recommended for exterior applications. The use of strippable films of adhesive paper or plastic is common practice during manufacture, transit, and installation to prevent surface damage or contamination. Such coverings can be applied over finished surfaces by the mill or surface finish supplier. Protective coatings or coverings on the fabricated parts shipped to the job site should always be removed as soon as possible after installation, and all adhesive residue should be removed completely. Careful specification of protective films can avoid adhesive residue. Adhesive chemistry can vary substantially and the film manufacturers advice should be sought in their removal.

For accumulations of oil or grease, proprietary

Table 3-5: Stainless Steel Selection Based on Site Score

Score	
0 to 2	Type 304 is generally the most economical choice.
3	Type 316 is generally the most economical choice.
4	Type 317L or a similar more corrosion resistant stainless steel is suggested.
≥5	A more corrosion resistant stainless steel such as 2205, 904L, 317LMN, or a 6% molybdenum austenitic stainless steel may be needed. The advice of a stainless steel corrosion specialist is suggested to confirm the severity of the location and to assist in stainless steel selection.

Table 3-6 – Estimated Site and Design Score

Points		Score
Section 1	Environment (select only the one highest applicable score)	
<i>Rural</i>		
0	Very low or no pollution	
<i>Urban Pollution</i> (light industry, automotive exhaust)		
0	Low	
2	Moderate	
3	High *	
<i>Industrial Pollution</i> (aggressive gases, soot, iron oxides, chemicals, etc.)		
3	Low or moderate	
4	High *	
Section 2	Coastal and/or Deicing Salt (chloride) Exposure (Select the one highest applicable score) <i>If there is exposure to both coastal and deicing salt, obtain assistance from a stainless steel atmospheric corrosion expert.</i>	
Coastal/Marine Salt Exposure only		
1	Low (1 to 10 miles (1.6 to 16 km) from salt water	
3	Moderate (100 ft to 1 mile (30 m to 1.6 km) from salt water	
4	High (<100 feet (30 m) from salt water)	
5	Marine (some salt spray or occasional splashing)*	
8	Severe Marine (continuous splashing)*	
10	Severe Marine (continuous immersion)*	
Deicing Salt Exposure only (distance from road or ground)		
0	No salt (chlorides) were detected on a sample from the site and no change in exposure conditions is expected	
0	Traffic levels on nearby roads are too low to generate road mist, or wind levels are too low to carry chlorides to the site, and no deicing salt is used on sidewalks	
1	Very low salt exposure (typically >600 ft (180 m) or 12 floors from salt source)**	
2	Low salt exposure (typically 100 to 600 ft (30 to 180 m) or up to 12 floors from salt source)**	
3	Moderate salt exposure (typically <100 feet (30 m) or 3 floors from salt source)**	
4	High salt exposure (Direct application or splash zone)*	
Section 3	Local Weather Pattern (select only one)	
-1	Temperate or cold climates, regular heavy rain (not sheltered)	
-1	Hot or cold climates with typical humidity below 50%	
0	Temperate or cold climate, occasional heavy rain (not sheltered)	
0	Tropical or subtropical, wet, regular or seasonal very heavy rain (not sheltered)	
1	Temperate climate, infrequent rain, humidity above 50%	
1	Regular very light rain or frequent fog	
2	Hot, humidity above 50%, very low or no rainfall***	
Section 4	Design Considerations (select all that apply)	
0	Boldly exposed for easy rain cleaning	
0	Vertical surfaces with a vertical or no finish grain	
-2	Surface finish is pickled, electropolished, or roughness ≤ Ra 12 microinches (0.3 micron)	
-1	Surface finish roughness Ra 12 micro inches < x ≤ Ra 20 micro inches (0.3 to 0.5 micron)	
1	Surface finish roughness Ra 20 < x ≤ 40 micro inches (0.5 up to 1 micron)	
2	Surface finish roughness > Ra 40 micro inches (1 micron)	
1	Sheltered location or unsealed crevices ***	
1	Horizontal surfaces	
1	Horizontal finish grain orientation	
Section 5	Maintenance Schedule (select only one)	
0	Not washed	
-1	Washed at least annually	
-2	Washed four or more times per year	
-3	Washed at least monthly	
	Total Site Score:	

* Potentially a highly corrosive location. Have a stainless steel corrosion expert evaluate the site.

** A sample from the site should be tested to determine if chlorides are present. Some locations of this type are exposed to chlorides but others are not.

*** If there is also salt or pollution exposure, have a stainless steel corrosion expert evaluate the site.

stainless steel degreasers, an organic solvent, mineral spirits, acetone, alcohol, benzene, citric cleaner, or a caustic solution such as trisodium polyphosphate can be used, followed by a water rinse. If more aggressive cleaning is needed to remove dirt deposits, a 200 mesh or finer calcium carbonate abrasive that does not contain chlorine should be

used, such as Bon Ami. It should be tested in a low visibility location first to ensure that it will not damage the finish and should be applied in the same direction as the polishing lines. Many common household abrasives are too harsh and will scratch the finish. They often also contain chlorides.

Refer to the following for more information on grade selection:

Nickel Institute publication No. 11 024, *Stainless Steels in Architecture, Building and Construction: Guidelines for Corrosion Prevention*, provides detailed information about evaluating the environment and selecting an appropriate product. Visit www.stainlessarchitecture.org.

Which Stainless Steels Should I Specify for Exterior Applications? and case studies from IMOA provide additional information on grade selection. Visit <http://www.imoa.info>.

If more corrosion resistance than Type 316 is needed, request the IMOA publication, **Practical Guidelines for Fabrication of Duplex Stainless Steels**, and Nickel Institute publication 11 021, **High Performance Stainless Steels**.

Additional comparative architectural metal corrosion data for different environments can be found in The **Construction Specifier** article, "Metals for Corrosion Resistance: Part II," (November 2000).

Chapter 4: Finishes for Carbon Steel & Iron

NAAMM/NOMMA AMP 500-06

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FINISHES FOR CARBON STEEL & IRON

General

It is well known that most substances tend to revert to their natural form, and among the architectural metals, carbon steel and iron are the most conspicuous examples of this rule. All of the common metals oxidize, or corrode, to some extent, but while the oxides forming on other metals generally inhibit the progress of further corrosion, the oxide, or rust, that forms on ordinary carbon steel and iron does not act in this way. Instead, if not prevented, oxidation progresses until the metal reverts to essentially the same state in which it was found in nature. It is generally the chief function of the finishes used on the common ferrous metals to counteract this tendency, to inhibit corrosion.

Some of the high strength, low alloy, copper bearing structural steels have been used in exposed applications such as building structural elements, curtain walls, bridge structures and transmission towers without applying paint for surface protection. These steels are referred to in the industry as “weathering steels.” When exposed to the weather they develop a relatively tight, adherent oxide film that tends to protect the surface against further oxidation or rusting, with time the film darkens and takes on a color ranging from dark reddish brown to a warm purple black. These surfaces, however, are not fully resistant to the effects of rain and serious rust staining can occur where water runs down and off the building on materials such as concrete.

While exposed surfaces have excellent durability, unexposed surfaces and interior surfaces do not develop sound oxide films and must be cleaned and painted with rust inhibiting primers in the same way that other carbon steels are protected. Today these steels are not often used for architectural applications.

The term “finish,” when used in reference to iron and steel, usually has a somewhat different connotation than when used in reference to the nonferrous metals. On the other metals it generally implies a surface treatment by mechanical or chemical means, and less frequently refers to an applied coating of some kind. With iron and steel

the reverse is true” most of the common finishes used on these metals are applied as coatings. Mechanical and chemical processes are extensively used for cleaning and surface preparation, but rarely as true finishes.

All types of additive coatings are used far more extensively on carbon steel than on other architectural metals, and for two basic reasons:

- 1) a protective covering is usually essential, as already explained, and

- 2) if an opaque coating is to be used on a metal it is only the coating itself which is seen, and for many applications costs can be minimized by using the most economical substrate having the necessary physical properties.

The ferrous metals satisfy this requirement. It should be noted, however, that the durability of many organic coatings under exposure to the elements is influenced by the durability of the base metal itself. Deterioration of the coating may be initiated at the interface between the coating and the substrate, due to the penetration of the coating by corrosives, and the corrosion resistance of the base metal therefore becomes a critical factor.

Probably the most common finish for architectural steel and iron is paint, a form of organic coating, applied by brush, spray, flow coating or dipping and frequently air dried. Relatively inexpensive metallic coatings of zinc, aluminum or combinations of these two metals, are applied to many steel building products, serving either as a base for subsequent organic coatings or as a final finish. Vitreous coatings in the form of porcelain enamel and plastic films as laminated coatings are also used.

With the exception of some hardware items, metallic coatings are not used on architectural products made of aluminum, copper alloys or stainless steel. On the other hand they are commonly applied to carbon steel and iron. For this reason metallic coatings are discussed in this section. The organic, vitreous and laminated coatings, being more general in their appropriateness, are given separate consideration in Applied Coatings,

SUMMARY OF TYPICAL IRON AND STEEL FINISHES

Finish	Finish Normally Supplied By		Relative Costs (on flat surfaces)
	Mill	Processor Fabricator or Finisher	
MECHANICAL			
As Fabricated	X		base
(hot rolled, cold rolled)			
Patterned		X	low to medium
(Other mechanical processes are generally for cleaning only.)			
CHEMICAL			
Cleaned only.....		X	very low
Conversion Coatings.....	X	X	low
(usually pretreatments for painting)			
COATINGS			
Metallic.....	X	X	medium to high
Organic (see Chapter 5).....	X		low to medium
Vitreous (see Chapter 5)		X	high
Laminated (see Chapter 5)	X		medium

The term PROCESSOR, as used here, refers to a "middleman" between the mill and the fabricator, who applies coatings, textures or other finishes to metal in bulk form, generally cut sheet or strip or coil stock. FABRICATOR refers to the producer of stock metal shapes or the manufacturer of the end-use product. He may also provide the final finish or he may send the fabricated products to a finisher who does the work. The FINISHER does not usually fabricate products, but provides finishes as specified, to products fabricated by others.

The RELATIVE COSTS indicated are necessarily approximate, for general guidance only. Exact costs vary considerably with quantity, type of product, quality of work, etc., and should always be verified.

Certain embossed patterns, because of their stiffening effect, permit the use of thinner metal, and this saving may in some cases offset their cost. In other cases patterned finishes involve extra cost.

Chapter 5. The table above summarizes the common usage of all of the various finishes commonly used on architectural iron and steel.

Mechanical Surface Treatments

As previously stated, true finishes applied by mechanical means are rarely if ever used on architectural iron and steel. Mechanical surface treatments are important, however, in preparing the metal to receive applied coatings, and these deserve consideration.

Mill Finishes

The **hot-rolled mill finish** on carbon steel is usually characterized by a tight mill scale and rust powder. For painting, all loose mill scale and rust particles should be removed, as they are likely to prevent complete adhesion and may provide focal points for incipient corrosion.

Cold-rolled surfaces should always be properly degreased before painting, and if they are extremely smooth, may also require roughening to insure good adherence.

Cleaning Methods

The following mechanical methods are used most extensively on carbon steel and iron to remove

mill scale, corrosion products and dirt, but they are not effective in removing oil and grease:

Hand cleaning (SSPCSP2)* is commonly accomplished with wire brushes, abrasive paper or cloth, scrapers, chisels or chipping hammers. Such methods are best adapted to spot cleaning, and are not recommended for use on large areas when more effective and cheaper methods are available.

Power tool cleaning (SSPCSP3)* A large variety of power driven brushes, grinders and sanders, mostly of the rotary type, are used for removing scale, rust, and dirt from heavy stock. Because of the severity of such cleaning methods, though, they are less appropriate for thin metal. This method of cleaning is more effective and more economical than hand cleaning for large surfaces, but may be slow as compared with other available methods.

Shot and sandblasting This is perhaps the best means of obtaining a clean surface suitable for painting, and may be done either wet or dry. Blasting should be used with caution on thin metal, however, because of the danger of its distorting the metal. These are relatively expensive processes and may be hazardous, so are usually used only where the highest quality work is required. All solid contaminants and even tight scale can be

removed, and besides being clean, the resulting surface is sufficiently roughened to ensure good paint adhesion.

**The Society for Protective Coatings has four different specifications covering different degrees of blast cleaning:*

SSPCSP5* Blast Cleaning to "White Metal"

SSPCSP6* Commercial Blast Cleaning

SSPCSP7* Brushoff Blast Cleaning

SSPCSP10* "Nearwhite" Blast Cleaning

Flame cleaning This method is not generally recommended.

It is appropriate only for heavy steel parts because the heat of the oxyacetylene torch used causes sheet and light members to buckle. It is effective in removing heavy rust and mill scale, but leaves tightly adhering oxides. All grease, oil and dirt should be removed before flame cleaning, and for best results the metal should be scraped and wire brushed after flame cleaning, and painted while still warm.

Chemical Treatments

Chemical treatments are not employed on architectural iron and steel to provide surface finishes, but are employed only to either 1) thoroughly clean the surface, without otherwise affecting it, or 2) to chemically convert the surface film so as to provide a good bond for applied coatings. Such treatments are briefly described in the following paragraphs.

Cleaning Processes

Three types of chemical cleaning process are in common use.

Pickling: (SSPCSP8)* This cleaning process very commonly used on ferrous metals, particularly sheet, bars and light shapes, to remove scale and oxide coatings. It consists of immersing the metal in a dilute acid solution, followed by rinsing first in water, then in other solutions and thorough drying.

Vapor degreasing: This process exposes the metal to vapors from chlorinated solvents such as trichloroethylene and perchlorethylene, and is performed in special degreasing machines, either by a batch method or as part of a continuous processing line. The chlorinated solvents are widely used in industrial cleaning operations, but have the disadvantages of being toxic and comparatively expensive, and they do not provide the degree of cleanliness that certain finishing operations such as plating may require.

Alkaline cleaning: This method is used when mineral and animal fats and oils must be removed. The metal may be sprayed with or immersed in

any of a number of proprietary or nonproprietary solutions, usually at elevated temperatures, after which it is rinsed with water. Caustic soda, soda ash, and alkaline silicates and phosphates are among the common cleaning agents used.

**Reference to detailed specification for this method, as established by the Society for Protective Coatings.*

Conversion Coatings

Conversion coatings are widely used, both on carbon steel and galvanized steel, to "convert", the chemical nature of the surface film, thus improving the bond for paint or other applied coatings. Acid phosphate solutions are most commonly used for such treatments. These are generally proprietary solutions, and produce a fine matte surface texture, usually slate gray in color.

Applied Coatings

As already indicated, the finishes used on architectural iron and steel are nearly always some form of applied coating, and by far the most common are the organic coatings such as paint. Metallic, vitreous and laminated coatings are also widely used, however, the relative extent of usage of these types probably being in the order named.

Since the organic, vitreous and laminated coatings are extensively used on other architectural metals also, it has seemed advisable to discuss these three coating types in a separate section, rather than as a finish for any one metal in particular, and this is done in Applied Coatings, Chapter 5. The use of metallic coatings for architectural purposes, though, is confined almost exclusively to iron and steel, and on this substrate they have many important applications for building products and accessories. Consequently this type of coating is discussed in some detail here, with special attention to zinc and aluminum.

Metallic Coatings

The metals most commonly used in the architectural field, for the coating of carbon steel, are the following:

Aluminum	Nickel
Cadmium	Terne metal
Chromium	(8090% lead, 2010% tin)
Copper	Tin
Lead	Zinc

The prime function of all such coatings is to

provide protection against corrosion, permitting the mechanical properties of steel to be used with reliable assurance of durability. Some of the coatings, however, have important decorative value as well.

As compared with other applied coatings, some of the metallic coatings provide unique protective value through electrolytic action. If the coating is anodic to, or less noble than the base metal, as in the case of zinc, it protects by “sacrificial action;” if cathodic, or more noble, its protective value is due to freedom from pinholes and to its own relative chemical inactivity in the environment to which it is exposed.

There are a number of different methods by which metallic coatings may be applied:

- a) **The Hot Dip Process**, in which the steel item, after being thoroughly cleaned, is immersed in a molten bath of the coating metal. Zinc, tin, lead, and aluminum are applied commercially by this process, and consequently in the architectural field this method of coating is by far the most widely used.
- b) **The Thermal Spraying Process**, often referred to as “metallizing,” which may be used with most of the metals listed above, and is extensively used for applying zinc and aluminum coatings. In this process the coating metal in the form of a wire or powder is fed into a specially constructed spray gun operated with compressed air and fuel gas. The gas is ignited at the nozzle, and the coating metal is melted as it is fed into the nozzle, then is projected at high speed against the surface to be coated. The coating adheres to the base metal by a combination of mechanical interlocking and metallurgical bonding. Thermal spraying is the only method of metallic coating that is practical for use in the field.
- c) **The Electroplating Process**, which has long been used to apply coatings of many different metals to steel. Zinc and cadmium are commonly applied by this method, and both are anodic to steel, but most other electroplated coatings are cathodic, providing protection by surface covering alone. The most common among these are nickel, chromium, nickel followed by chromium, and copper followed by nickel or by nickel and chromium.
- d) **The Cladding Process**, which produces bime-

tallic products consisting of a steel or other metal core, covered with a thin sheet layer of the coating metal. Copper cladding may be applied by casting the copper about a heated steel core mounted in a covered mold out of contact with the air, by dipping the steel core into a bath of molten copper, or by depositing the copper electrolytically. Stainless steel cladding may be accomplished by electrowelding stainless steel onto the carbon steel core, or by placing the carbon steel between two sheets of stainless steel and rolling. Aluminum cladding is accomplished by rolling flat steel, cleaning it thoroughly, and placing it between two sheets of aluminum and either cold rolling or warm rolling at between 600 °F (315°C) and 700°F (370°C) “Alclad” aluminum stock is also produced by this method, using an aluminum alloy core sheet and very thin cladding of high purity aluminum. Also, by a roll bonding process developed in Great Britain, steel may be clad with lead to provide both the corrosion resistance and the sound attenuation properties of lead.

- e) **The Cementation Process**, by which the coating metal is alloyed into the surface layers of the steel. A variety of different processes are used, including one by which small articles are zinc-coated by packing them in zinc dust in an airtight revolving container and heating to a temperature in the neighborhood of the melting point of zinc.
- f) **The Fusion Welding Process**, which involves either depositing weld metal under a slag covering by the electric arc method, or fusing the surfaces of two bodies of metal in contact, by passing a high density current. These initial steps are followed by heating and rolling.

Painting with heavily mineral-pigmented paints has also been found to produce corrosion resistance comparable to some of these metallic coating processes, and the protective value of zinc-rich paints is particularly significant. While this is not technically a metallic coating, but a paint, and is therefore discussed in Applied Coatings, Chapter 5, the merits of this means of providing protection from corrosion should be recognized at this point.

Most of the metallic coating of building and architectural products is done by the hot-dip and electroplating processes, and aside from hardware

items and lighting fixtures, by far the most common of these are zinc coatings, aluminum coatings and aluminum-zinc coatings. These types of finishes, therefore, deserve detailed consideration.

Zinc Coatings (Galvanizing)

Zinc coatings protect the steel base from corrosion by a twofold action. In addition to providing a protection barrier which seals out moisture and other airborne corrosives, they also protect by galvanic action. The anodic relationship of zinc to iron is such that even when the iron is exposed by small breaks in the coating, the zinc still provides protection, being slowly consumed in these limited areas by sacrificial action.

Zinc coatings are applied by several methods. In order of their commercial importance, these are the hot-dip method, electrodeposition (electrogalvanizing), thermal spraying, and several proprietary processes. The effective protective life of these coatings depends primarily on their thickness, but the uniformity and adherence of the coating is also essential to good performance. Regardless of the method of application, the heavier the coating, the longer will be the rust-free life of the metal. Its adherence, especially under mechanical deformation, must also be considered, because flaking or peeling of the coating may expose more base metal than can be protected by anodic action.

For architectural uses, two types of zinc coated sheets are available:

- 1) Galvanized sheets with ordered coating class G90 (Z275) (Minimum Check Limit TripleSpot Test 0.90 oz/ft² (275 g/m²) of sheet) or heavier, for use where exposures require durable protection.
- 2) Electrolytically zinc-coated sheets with coatings of 01Z (03G) of minimum 0.01 oz/ft² (3 g/m²) of sheet, usually requiring additional painting for satisfactory durability.

Two variations of the hot dip method are used; one for continuous sheet and strip, the other for fabricated shapes. Continuous coatings are quite uniform and ductile, and the most commonly produced is the G90 (Z275) coating, which has a thickness of approximately 3/4ths of one mil on each side. The G90 (Z275) coating is the grade most frequently used in architectural applications, but heavier coatings, up to 3.6 oz/ft² (1100 g/m²), can be supplied for use where severe exposures call

for increased durability. Table 4-1 lists the commonly available coating thicknesses and weights of commercial galvanized sheet.

After-fabrication galvanizing is a versatile process by which articles ranging in size from nuts and bolts to structures 1500 ft (460 m) in height have been protected. ASTM standards A 123/A 123M, A 153/A 153M, and A 653/A 653M provide for minimum coating weights up to 3.6 oz/ft² (1100 g/m²) depending on material thickness. Molten zinc baths in the 50-60 ft (15-18 m) range are available, allowing materials up to 90 ft (28 m) in length to be galvanized by double end dipping. The ability to accommodate these sizes, together with the ability to bolt or weld prefabricated structures after galvanizing, permit most any structure to be galvanized. Complex shapes and open vessels may be galvanized inside and out in one operation.

All types of plain carbon steel, some low-alloy steels, and iron and steel castings can be hot-dip galvanized after fabrication, providing a thick zinc and zinc alloy coating that is metallurgically bonded to the base metal. The molten zinc is applied in even thickness on edges and flat surfaces, covering corners and seams and penetrating recesses to give protection to potential corrosion sites. Though galvanizing is more tolerant of surface defects in the substrate than most other coating processes, the absence of defects will ensure a better quality coating, particularly where appearance is important. Because the rate of zinc corrosion relative to that of steel is known for many types of atmosphere, a specific maintenance free life can usually be predicted. The standard galvanized coating applied after fabrication lasts up to 75 years, even in industrial, marine or urban atmospheres.

Lightweight coatings of only 0.01 oz/ft² (3 g/m²) are normally applied by electroplating rather than hot dipping. Electroplating is used for small articles such as screws and other miscellaneous hardware items. Coating uniformity by this process may be poor, however, and most large scale electroplating is limited to strip and wire. Electrodeposited zinc generally has a fine matte surface which creates a good base for paint. While such coatings will protect the steel base from rusting during storage and fabrication, they are not heavy enough to provide effective protection for outdoor use or interior applications exposed to moisture. These light coatings should be specified only for painted parts or for mild interior exposures.

Coating Thickness

Coating thickness (measured as coating weight in ounces per square foot or grams per square meter) is an important factor in the effective application of galvanized sheet. The coating weight should be chosen carefully, with full attention to the fabrication method and type of environment in which the sheet will be expected to serve. In general, the effectiveness of the zinc coating to protect the steel substrate from corrosion in any given environment is directly proportional to the coating thickness. For example, for any spe-

cific set of environmental conditions, a G90 (Z275) coating will last about 50 percent longer than a G60 (Z180) coating, maintenance, painting and all other factors being equal.

Factors in addition to corrosion resistance must be considered when selecting coating thickness. For example, the adherence of the coating generally is inversely proportional to the thickness; therefore, a thin coating is more desirable for applications involving high amounts of forming. Also, spot welding becomes more difficult as the coating thickness increases.

TABLE 4-1 AVAILABLE COATING THICKNESSES AND WEIGHTS OF COMMERCIAL GALVANIZED SHEETS AND COIL

Coating Thickness - English Units (Metric Units)			
ASTM A653 Coating Designation	Minimum Coating Weight oz/sq ft (g/m ²)		
	Triple Spot Average Both Sides ⁽²⁾	Single Spot Test	
		One Side	Total Both Sides
G210 (Z600)	2.10 (600)	0.72 (204)	1.80 (510)
G185 (Z550)	1.85 (550)	0.64 (190)	1.60 (415)
G165 (Z500)	1.65 (500)	0.56 (170)	1.40 (425)
G140 (Z450)	1.40 (450)	0.48 (154)	1.20 (385)
G115 (Z350)	1.15 (350)	0.40 (120)	1.00 (300)
G90 (Z275)	0.90 (275)	0.32 (94)	0.80 (235)
G60 (Z180)	0.60 (180)	0.20 (60)	0.50 (150)
G40 (Z120)	0.40 (120)	0.12 (36)	0.30 (90)
G30 (Z90)	0.30 (90)	0.10 (30)	0.25 (75)

1 oz/ft² coating weight = 1.7 mils coating thickness
7.14 g/m² coating weight = 1 mm coating thickness

Courtesy of US Steel Corp.,
Pittsburgh, PA

1. The coating designation number is the term by which this product is ordered.
2. The weight of coating in oz. per sq. ft. refers to the total coating on both surfaces. The triple spot average encompasses an edge-center-edge sampling to determine adequate coverage across the sheet width. Typically, about half this coating is on each side.

Design Considerations for Galvanizing

In order to produce optimum quality galvanizing and to ensure reasonable coating costs certain rules must be followed in the design of products which are to be hot-dip galvanized after fabrication.

Drainage: For effective galvanizing, cleaning solutions and molten zinc must flow into, over, through and out of the fabricated product without undue resistance. Failure to provide for this free, unimpeded flow is a frequent cause of problems. Improper design of drainage results in galvanizing of poor appearance and excess buildup of zinc. These are unnecessary and costly.

Venting: It is mandatory that tubular fabrications and hollow structurals be properly vented. Proper galvanizing requires that the inside, as well as the outside, be completely cleaned and coated with zinc. To achieve this, air and frothy fluxes must be allowed to flow upward and completely out. Cleaning solutions and molten zinc must be allowed to flow in and completely wet the surfaces. Since items to be galvanized are immersed and withdrawn at an angle, the vent holes should be located at the highest point and drainage holes at the lowest point in each member. Vent holes can be closed with drive caps or plugs after galvanizing.

Distortion: Some fabricated assemblies may distort at the 850°F (455°C) galvanizing temperature as a result of relieving stresses which were induced during steel manufacture and subsequent fabricating operations.

Following are some recommendations to minimize distortion:

- Where possible use symmetrical rolled sections. I-beams are preferred to angles or channels.
- Use parts in an assembly that are of equal or near equal thickness, especially at joints.
- Bend members to the largest acceptable radii to minimize local stress concentration.
- Accurately preform members of an assembly so that it is not necessary to force, spring or bend them into position during joining.
- Continuously weld joints using balanced welding techniques to reduce uneven thermal stresses.

- Avoid designs which require double dip galvanizing or progressive galvanizing.
- Consult the galvanizer regarding the use of temporary bracing and/or reinforcing to minimize or prevent warpage and distortion during galvanizing.

Guidelines for minimizing warpage and distortion are given in *ASTM A 384/A384M, Standard Practice for Safeguarding Against Warpage and Distortion During Hot-Dip Galvanizing of Steel Assemblies*. These guidelines are also generally applicable to the hot-dip coating of steel with other metals.

Special procedures are also recommended for weldments and castings. However, aside from pointing out that there are basic design considerations which must be taken into account when galvanizing steel assemblies, it is not the purpose of this manual to cover product design requirements and manufacturing processes in detail. *ASTM A 385, Standard Practice for Providing High Quality Zinc Coatings (Hot-Dip)*, covers various aspects of designing for hot-dip galvanizing. Excellent detailed information on all aspects of hot-dip galvanizing is available from the American Galvanizers Association.

Special Finishes and Paint Pretreatments for Galvanized Sheets

Most of the galvanized sheets used by industry are supplied with the regular “spangled” finish produced by the continuous galvanizing line. For architectural applications, however, certain other finishes may be required, to improve the bonding of paint or other organic coatings, and these may be obtained on special order.

Wipe Coated Galvanized Sheets are hot-dipped sheets on which the zinc is wiped down as the steel leaves the zinc pot. The resulting product has a light zinc-iron alloy coating of approximately 0.1 oz/ft² (30 g/m²) to 0.5 oz/ft² (150 g/m²) and does not have a spangle. When required, it is produced to be suitable for painting after cleaning. These sheets may have certain longitudinal lines resulting from the wiping operation.

Galvannealed Sheets are hot-dipped sheets which have been heat treated after coating to produce a dull gray zinc-iron alloy surface which is free of the typical spangles. Although these sheets can be painted without further surface preparation except for normal

cleaning, surface treatment is usually recommended to ensure good paint adhesion and durability. The surface alloy lacks ductility, however, and powdering of the coating sometimes occurs in local areas of severely formed parts.

The most widely known and used of the pretreatment processes is a hot phosphate treatment in which a chemical solution, or a series of chemical solutions, is allowed to react with the zinc of the coating to produce a thin crystalline surface composed largely of zinc phosphate. This film is measurable and usually falls within the range of 0.02 oz/ft² (6 g/m²) to 0.03 oz/ft² (9 g/m²) of sheet. The phosphatizing process renders the surface suitable for immediate painting without further preparation except for normal cleaning, and since it is a surface treatment only, the other characteristics of the coated sheet are the same as those of standard hot dipped sheets.

Another paint pretreatment used by fabricators is called a “wash primer.” This is a material which is mixed with phosphoric acid and applied

like a very thin coat of paint, and if used freshly mixed usually gives good results. It can be purchased from industrial paint suppliers, or directly from some paint manufacturers. (See SSPC-PS 27.00)

Paintability of Untreated Galvanized Surfaces

Galvanized surfaces frequently are painted to increase their service life or improve their appearance. Untreated commercial galvanized finishes are generally not suitable for painting with “ordinary” paints, however, unless they have been allowed to weather in the atmosphere for several weeks or months. Recent research, however, has shown that with the proper paint even unweathered surfaces can be painted satisfactorily.

A study conducted by the Committee of Galvanized Sheet Producers, with the assistance of the Society for Protective Coatings, has produced important new information regarding the painting

PRECAUTIONS

Regarding the Use of Weathering Steel and of Galvanized Finishes

Extreme caution should be exercised in detailing the use of weathering steel. Water running off weathering steel carries minute particles of iron oxide which have a tendency to adhere to the wetted surface and will be evidenced by discoloration of these surfaces.

Great care should also be given to the detailing of weathering steel surfaces that will not be boldly exposed to the atmosphere. Interior surfaces, surfaces covered by gaskets, all internal members, and faying surfaces which may be in contact with moisture resulting from condensation or water penetration must have protective coatings; otherwise advanced corrosion may occur within a short period of time.

The use of weathering steel is not recommended in locations where it may be continuously wet, or subject to appreciable amounts of salt spray.

In specifying galvanized sheets the most important consideration is the coating thickness or weight needed. The standard G90 coating (minimum of 0.90 oz. per sq. ft. of sheet) will normally be adequate, but for critical exposures such as aggressive industrial atmospheres, heavier coatings (e.g., G165, G185, G210 or G235) are recommended.

Zinc coatings will be burned off by ordinary welding operations. The coating can be restored, to provide excellent corrosion protection, by thermal spraying, by painting with zinc dust, zincoxide or zinc rich paint, or by the use of certain proprietary products.

Zinc-coated surfaces in contact with concrete containing cinders or salty aggregates, or with oak or red cedar wood, should be protected by a coat of bituminous paint.

Galvanic corrosion is likely to result if a zinc coating is in contact with more noble metals such as copper or copper alloys.

Zinc-coated items should not be left standing on cinders at the building site, as the soluble sulphites are very corrosive to zinc.

Zinc-coated items should not be stored in packs or bundles where they may be subject to moisture due to condensation or other causes.

of galvanized surfaces. While it confirms that mill treatments such as bonderizing and galvannealing result in superior paint-holding qualities, this study has also shown that untreated sheets, both new and weathered, can be painted with a minimum of preparation and with excellent adherence by following a few simple rules. In brief, the results of the study are summarized as follows:

1. Zinc dust-zinc oxide and Portland cement-in-oil paints provide the best results. Latex or other proprietary paints specifically intended for galvanized sheets can also be used.
2. Quality of paint is of great importance; it should be purchased only from reputable manufacturers.
3. Chemical treatment of galvanized sheets by the mill to minimize "wet storage stain" (not to be confused with special finishes or pretreat-

ments) has a negligible effect on the adhesion of the recommended paints. When materials galvanized after fabrication are to be painted soon after they are galvanized, no post-treatment of the surface should be specified.

4. Weathering is desirable, but not necessary, to achieve good adhesion, when the correct paint is used.

Aluminum Coatings (Aluminizing)

The aluminizing of steel is a much newer process than galvanizing, and aluminum coated steel sheets for architectural uses have been commercially available only since 1952. But since such sheets offer the strength of steel in combination with the corrosion resistance of aluminum they have found acceptance in many building applications.

**TABLE 4-2 AVAILABLE THICKNESSES
AND WEIGHTS OF TYPE 2 ALUMINIZED SHEET AND COILS**

TYPE 2: Hot-dip coated with commercially pure aluminum. It is intended principally for applications requiring atmospheric corrosion resistance. Type 2 may ultimately be manufactured into corrugated roofing and siding, grain bins, air conditioner housings and drying ovens.

ALUMINIZED SHEET TABLE <i>Thickness & Weight Equivalents</i>				
Thickness in Inches			Pounds Per Sq Ft	
Mean	Low	High	Type 1	Type 2
.138	.129	.147	5.598	5.571
.123	.114	.132	4.977	4.950
.108	.099	.117	4.365	4.338
.093	.085	.101	3.753	3.726
.079	.071	.087	3.182	3.115
.071	.065	.077	2.856	2.829
.064	.058	.070	2.570	2.543
.058	.053	.063	2.325	2.298
.052	.047	.057	2.081	2.053
.046	.041	.051	1.836	1.809
.040	.036	.044	1.591	1.564
.037	.033	.041	1.469	1.441
.034	.030	.038	1.346	1.319
.031	.027	.035	1.224	1.197
.028	.024	.032	1.101	1.074
.025	.021	.029	0.979	0.952
.022	.019	.025	0.857	0.829
.020	.017	.023	0.775	0.748
.019	.016	.022	0.764	0.707
.017	.014	.020	0.653	0.625
.016	.013	.019	0.612	0.585

Courtesy of Block Steel Corp., Skokie, IL

Two grades of aluminum-coated steel are available:

Type 1 has an aluminum-silicon coating which provides excellent resistance to a combination of corrosion and high temperatures (to 1250°F), and has important uses in the automotive industry.

Type 2, the architectural grade, has a commercially pure aluminum coating which exhibits excellent resistance to atmospheric corrosion, but is not recommended for use at temperatures above 900°F (480°C).

Aluminum coatings are applied by the hot dip process. Unlike zinc coatings they offer no significant protection by anodic action in most environments, but they do provide a durable barrier which prevents moisture and other corrodents from reaching the base metal. Cut edges of coated sheets are vulnerable to some rusting and should usually be protected, but the rusting is said to be limited to the edge itself, and no rust bleeding or undercutting of the aluminum occurs. In certain environments the coating can be preferentially corroded by metals lower in the galvanic series, and the same protective measures against galvanic corrosion as those recommended for aluminum are generally advised.

Aluminized steel weathers much the same as aluminum, the general corrosion resistance of the coating in normal atmospheric exposures being similar to that of aluminum alloy 1100.

Commonly available sizes of aluminized steel sheets are listed in Table 4-2.

Aluminum Zinc Coatings

The coating of steel with aluminum and zinc combines the protective properties of both of these metals. It is produced by hot dip coating cold rolled sheet steel on a continuous line. Aluminum provides the barrier protection and long life of aluminum coatings while the zinc provides the sacrificial or galvanic protection of zinc coatings at cut or sheared edges. This combination of coatings produces a highly corrosion resistant sheet steel.

Chromate pretreatments for prepainted sheets are recommended instead of zinc phosphates or complex oxide pretreatments typically used for prepainted galvanized steel. Chromate pretreatments result in improved resistance to edge creep and provide better corrosion resistance than other types of pretreatment.

New epoxy primers, approved by the manufacturers of aluminum zinc coated steels, should be used to improve paint adhesion and to overcome edge creep without adversely affecting other properties.

Aluminum zinc coated sheet steels with hot-dip coated and prepainted edges can be supplied. Such protection produces outstanding resistance to corrosion originating at the edge.

TABLE 4-3 FINISHES FOR CARBON STEEL HARDWARE

Finishes for architectural hardware made of carbon steel are generally designated by finish code numbers of the Builders Hardware Manufacturers Association, BHMA. A variety of finishes are available. Listed below are those most commonly in use today. Since U.S. Finish Designations occasionally appear in specifications, the nearest U.S. equivalent of the BHMA number is shown on the list. For a complete listing and description of hardware finishes refer to ANSI/BHMA A156.18, American National Standard for Materials and Finishes.

Code No.	Nearest US Description	Equivalent
604	Zinc plated, dichromate sealed	N.A.
631	Flat black coated	US19
633	Satin brass plated, clear coated	US4
637	Bright bronze plated, clear coated	US9
639	Satin bronze plated, clear coated	US10
640	Oxidized satin bronze plated, oil rubbed	US10B
649	Light oxidized bright bronze plated, clear coated	US20
650	Dark oxidized statuary bronze plated, clear coated	US20A
651	Bright chromium plated over nickel	US26
652	Satin chromium plated over nickel	US26D

Specification Standards for Galvanizing

- ASTM A 123/A 123M – Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products.
 - ASTM A 153/A 153M – Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware.
 - ASTM A 653/A 653M – Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process.
 - ASTM A 879/A879M – Specification for Steel Sheet, Zinc Coated by the Electrolytic Process for Applications Requiring Designation of the Coating Mass on Each Surface.
 - ASTM A 924/A 924M – Specification for General Requirements for Sheet Steel, Metallized by the Hot-Dip Process.
 - ASTM B 633 – Specification for Electrodeposited Coatings of Zinc on Iron and Steel.
-

REFERENCES

For more detailed information on the subject of metallic finishes for carbon steel, the following references are suggested:

AWS C2.23M/C2.23 Specification for the Application of Thermal Spray Coating (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel, American Welding Society, www.aws.org.

Recommended Details of Galvanized Structures, American Galvanizers Association, Centennial, CO, www.galvanizeit.org.

Painting Galvanized Structural Steel, American Galvanizers Association, Centennial, Colorado, www.galvanizeit.org.

The Design of Products to be Hot Dip Galvanized after Fabrication, American Galvanizers Association, Centennial, CO, www.galvanizeit.org.

Systems, Standards, Guides, and Specifications, The Society for Protective Coatings (formerly the Steel Structures Painting Council) Pittsburgh, PA, www.sspc.org.

Surface Preparation Specifications, ASTM, www.astm.org.

Chapter 5: Applied Coatings

NAAMM/NOMMA AMP 500-06

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Applied Coatings

General

One usually looks at paint as a way to add an attractive color (appearance) to a surface. Metals, including coated steel sheet products, are often painted for this reason. But, in addition to the use of paint to provide color, there is another reason to paint coated steel sheet. That reason is: additional corrosion protection!

Coatings may be described by their appearance (e.g., clear, pigmented, metallic, or glossy) and by their function (e.g., corrosion protective, abrasion protective, skid resistant, decorative, or photosensitive). Coatings may be distinguished as organic or inorganic, although there is overlap. For example, many coatings consist of inorganic pigments dispersed in an organic matrix (the binder).

This chapter is limited to coatings with organic binders that are applied purposefully to a substrate. Electroplated copper, nickel, and zinc coatings are not discussed. Discussion of organic coatings is further restricted to those materials that can be historically traced back to paints.

What is the difference between a coating and paint? Not much—the terms are often used interchangeably. However, it has become a common practice to use coatings as the broader term and to restrict paints to the familiar architectural and household coatings and sometimes to maintenance coatings for doors and windows, bridges and tanks. Still another common term that is essentially a synonym for coatings and paint is finish.

Coatings are used for one or more of three reasons: (1) for decoration (2) for protection, and/or (3) for some functional purpose. The low gloss paint on the ceiling of a room fills the decorative need, but it also has a function: It reflects and diffuses light to help provide even illumination. The coating on the outside of an automobile adds beauty to a car and also helps protect it from rusting. While the public most commonly thinks of house paint when talking about coatings, all kinds of coatings are important throughout the economy, and they make essential contributions to most high-tech fields.

Since about 1965, the pace of technical

change has increased. A major driving force for change has been the need to reduce VOC (volatile organic compound) emissions because of their detrimental effect on air pollution. The drive to reduce VOC emissions has also been fueled by the rising cost of organic solvents. Other important factors have also accelerated the rate of change in coatings. Increased concern about toxic hazards has led to the need to change many raw materials that were traditionally used in coatings. Furthermore, manufacturers often want their coatings modified so that they can be used at faster production rates, baked at lower temperatures, or changed in color. Product performance requirements have tended to increase, most notably is the need for increased effectiveness of corrosion protection by coatings.

Composition of Coatings

Organic coatings are complex mixtures of chemical substances that can be grouped into four broad categories: (1) binders, (2) volatile components, (3) pigments, and (4) additives.

Binders are the materials that form the continuous film that adheres to the substrate, binds together the other substances in the coating to form a film, and presents an adequately hard outer surface. The binder governs, to a large extent, the properties of the coating film. Vehicle is a commonly encountered term. It usually means the combinations of the binder and the volatile components of a coating. Today, most coatings, including water-borne coatings, contain at least some volatile organic solvents. Exceptions are powder coatings and radiation curable coatings.

Volatile components are included in a majority of coatings. They play a major role in the process of applying coatings, they are liquids that make the coating fluid enough for application, and they evaporate during and after application.

Pigments are finely divided insoluble solids that are dispersed in the vehicle and remain suspended in the binder after film formation. Generally, the primary purpose of pigments is to provide color and opacity to the coating film. However,

they also have substantial effects on application characteristics and on film properties. While most coatings contain pigments, there are important types of coatings that contain little or no pigment, commonly called clear coats, or just clears. Clear coats for automobiles and transparent varnishes are examples.

Additives are materials that are included in small quantities to modify some property of the coating. Examples are catalysts for polymerization reactions, stabilizers, and flow modifiers. Most coatings are complex mixtures. Many contain several substances from each of the four categories, and each substance is usually a chemical mixture.

The number of possible combinations is limitless. The number of different applications is also limitless.

Explanation of Terms

Trade sales paint is the term used in the coatings industry to designate those coating products that are sold over the counter and usually applied in the field. However, coatings intended for application to industrial structures are not included in this category.

Industrial finishes is a term used to designate either those coatings that are applied in the factory or those used for industrial maintenance.

Enamel is a type of paint distinguished for its gloss. Enamels differ from flat paints by having a higher percentage of liquid binder, which usually makes them harder, smoother, less porous, more durable, and better able to withstand scrubbing. Commonly, they are either gloss or semi-gloss, the gloss enamels having the higher percentage of binder and the lower percentage of pigments; flat enamels contain a flattening agent to eliminate the gloss. Most enamels are solvent reduced, but in recent years field applied latex (water-reduced) semigloss enamels have been gaining in use.

Lacquer is a clear or colored solution coating that dries by solvent evaporation alone. Drying may take place either at ambient temperature or with the aid of applied heat.

An air-dry coating is any coating that dries or is chemically cured at ambient temperatures,

either in the field or in a controlled factory environment.

A baking coating is a coating composition, either clear or pigmented which requires an elevated temperature either to accelerate solvent evaporation or to cure or crosslink the film to its hard, completely polymerized form.

Plural component coatings begin forming film by chemical reactions after mixing two or more components. The reactions can proceed either at room or at elevated temperatures. In theory neither component reacts on its own, that is, it requires the other part to yield a dry coating film. These coatings generally possess superior durability, adhesion and corrosion protection properties.

Waterborne coatings are essentially the same as conventional coatings except that the resin (binder) has been suspended in water through the use of surfactants and that the majority of solvents are replaced by water. Waterborne coatings can either be air-dry or chemical crosslinking. Due to lower VOCs waterborne coatings are more environmentally friendly than solvent-based paints. Most chemistries such as epoxy, polyurethane, alkyds, polyesters, etc., can be made into waterborne coatings.

Powder coatings, as the name implies, are coatings in solid form. The fine particles of a one-part coating is sprayed onto metals and some plastics. The powder adheres to the substrate by electrostatic forces.

There are two types of powder coatings. Thermoplastic and thermosetting. Thermoplastic powders include chemistries such as nylon, polyethylene and vinyl. Thermoplastic powders are sprayed onto preheated parts (or dipped into clouds of powder in a fluidized bed) followed by further baking in the oven at 350-450 F. Upon cooling a tough coating film much like conventional coating is obtained. The average film build is about 200 microns (8 mils).

Thermosetting powder coatings include epoxy, polyurethane, polyester and any combination thereof. The fine powder is usually sprayed electrostatically and baked at temperatures in the range of 275-450 F. The average film build is about 50 microns (2 mils).

Essential Properties of Coatings

Certain desirable properties are present to a varying degree in all coatings, depending upon their composition. These properties can be selectively controlled by adjusting the components of the formula. Very often, though, when one property is improved, another is weakened; hence compromises are frequently necessary. The user may find it advisable to accept somewhat less than highest performance in respect to one property in order to obtain better performance in respect to another.

Some of the more important properties of metal coatings and their roles in performance are briefly outlined in the following paragraphs. The intended use determines which properties are pre-eminent in any given case. Hence the coating with properties that most closely meet the requirements should be selected for maximum performance.

Flow relates to the ease with which a coating can be applied. Too much ease of flow may result in a runny, poor hiding film, especially on vertical surfaces; poor flow may cause brush or roller drag, which slows application, increases labor costs, and results in surface imperfections. To help assure thick films where needed, bodying agents (rheology control agents) may be used to reduce flow and aid film build.

Leveling refers to the ability of a coating to smooth out after application by brush, roller or spray gun. Coatings should spread evenly over the surface, without valleys between brush marks, stipple from rollers or “orange peel” effects from spraying. Their protective value is reduced in all such visible depressions.

Film thickness is directly related to protection against moisture and corrosive environments as well as other potential sources of damage. Naturally, as film build, or thickness increases, coverage per gallon decreases. A specified film build may result from a single coat or from multiple coats depending on the solids content of the coating and the thickness specified. Most coatings provide dry films of from 1.0 to 2.5 mils (0-62.5 microns) per coat, but high solids coatings, such as plastisols, can provide coatings between 4.0 to 8.0 mils. For exposure to highly corrosive atmospheres a total of 1.0 mils, usually in more than one coat, is gen-

erally considered necessary. However, protection is also a function of the properties of the coating resin. For example, a 3.0 mil epoxy coating may be superior to a 7.0 mil linseed oil alkyd coating. Manufacturers standards should be consulted for properties of coatings which they supply.

Spreading rate depends on the desired film thickness and the amount of hiding pigments in the coating. Where good hiding property is a prime requirement, a properly pigmented flat coating should hide at a spreading rate of 400 to 500 square feet per gallon in one coat. If surface protection is critical, as with an anticorrosive paint, the required coating may have a spreading rate of only 150 square feet per gallon and two or three such coats may be required. High build coatings are usually preferred in such instances.

Permeability of coatings, or the ability of moisture and gases to work their way through, is diminished by increasing film thickness and increased by adding extender pigment or certain hiding pigments. Thick coatings add to substrate protection. Each combination of binder and pigment has an optimum relationship for limiting permeability most effectively. This is called the Critical Pigment Volume Concentration (CPVC), and indicates the percentage of pigment that the binder can completely wet and bind up. As the percentage of pigment exceeds this concentration each added pigment particle, as a general rule becomes a pathway for moisture or corrosive chemicals. Permeability is also reduced by multiple coatings.

Adhesion of a coating to a substrate must be tenacious if cracking and peeling are to be avoided. Surfaces must be free of contamination before applying coatings if satisfactory adhesion is to be obtained. The importance of clean surfaces to good adhesion cannot be overemphasized. In some instances abrasive blasting is needed to obtain suitable surface conditions. Aluminum and other non-ferrous metals may require chromate treatments or wash primers to ensure proper adhesion.

Flexibility is essential if the coated material is to be subjected to forming processes. Even if this is not a requirement, any coating to be used on the exterior of a building must be able to withstand

dimensional changes caused by expansion and contraction under thermal stress.

Abrasion and impact resistance is desirable in all coatings, to minimize physical damage to the film, both between the application of successive coats and after the finished product is used.

Stain resistance has gained increasing importance in recent years because of a widespread application of graffiti in public places. Very hard undercoats, usually topped with clear solvent resistant ultra hard polymers, are now available to resist penetration of inks and the solvents carrying them.

Weatherability of a metal coating depends on its resistance to chalking, which eventually deteriorates the coating film; to color changes caused by ultraviolet rays; to wind driven rain, to salt spray, if near the sea, and to wind borne chemicals.

Weldability of a primer is the ability of the coating to withstand the heat of welding without losing its protective value.

Film Formation-Drying and Curing

Dry time is significant because it indicates the “safe” period, when the threat of surface contamination has ended and when a successive coat may be applied. There are three mechanisms of drying.

1) Drying through the evaporation of solvents or water. All lacquers and varnishes follow this mechanism. There are also two significant stages for this type of drying:

A) set-to-touch, or surface drying, when dust and surface contaminants will have no effect, and

B) through dry, when drying is complete to the substrate and recoating can proceed. Too rapid drying, in addition to affecting leveling, also affects “wet

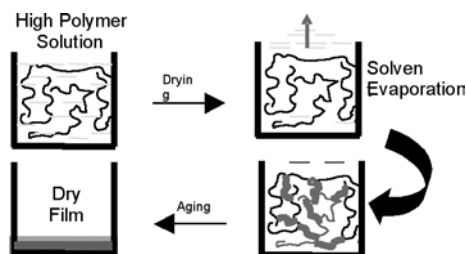


Figure 5-1. Drying by solvent evaporation.

edge,” or the ability of the applied coating to stay wet so that when applied to an adjoining area it will blend with the edge of the first coated area without showing an overlap. Schematic representation of film formation by drying is given in Figure 5-1.

2) Drying of latex systems through evaporation of water, solvents and coalescence. While most latex systems follow the two steps of set-to-touch and surface drying, molecules within the matrix continue coalescing until a cohesive film is obtained. This is analogous to through-dry in the solvent-borne systems but usually takes longer than those systems. This process, depending on the chemistry of systems, may be slow or fast. In either case, the film is dry to touch. In general recoating will require a longer wait than the solvent borne systems. Schematic representation of film formation from a latex solution by coalescence is given in Figure 5-2.

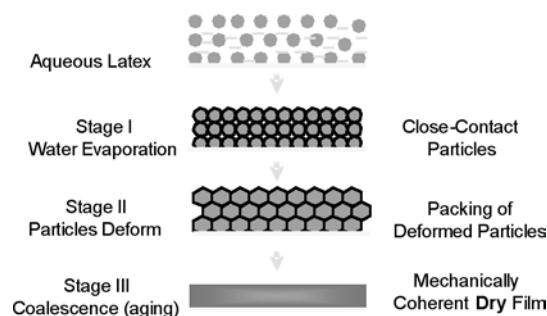


Figure 5-2. Coalescence in latex systems.

3) Drying by curing or chemical reactions. These reactions are commonly called cross-linking reactions. Similar to the above two categories, the film formation is a function of time and temperature. In general, chemically crosslinked systems are more weatherable, durable, corrosion and solvent resistant than simple air-drying lacquer type coatings. Drying oils and some alkyd coatings are one-part coatings that crosslink when exposed to environmental oxygen. Most room temperature crosslinking coatings are two-part systems. In general the film formation begins soon after the parts are mixed together and continues for several hours or days. Most two part systems are formulated to provide a set-to-touch state in a matter of minutes or hours while the through cure (completely crosslinked) may take additional days. Exposing two part systems to elevated temperatures will speed up the cure. Schematic representation of film formation by chemical crosslinking is given in Figure 5-3.

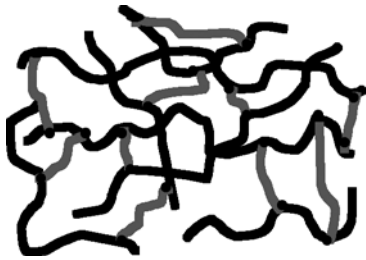


Figure 5-3. Chemical crosslinking.

Chemical crosslinking one component coatings requires elevated temperatures to cure. In general, the higher the temperature, the faster the cure and film property development. Thermosetting powder coatings, one part epoxy, polyurethane, polyester melamine coatings require temperatures in the range of 275-420° F for a complete cure.

Powder coatings are deposited on an object as finely divided solids consisting of resinous material, additives to aid performance, and colorants if desired. The object to be coated is electrically grounded if the powder is to be electrostatically sprayed, and may be heated before or after the powder is applied. A less frequently used procedure is the fluidized bed process, in which the object is heated and immersed in an enclosure in which the powder is “fluidized” by a gentle air current. Coalescence of the powder particles on the heated surfaces, in either method, leaves a smooth, hard coating. Schematic representation of film formation in powder coatings is given in Figure 5-4.

Adhesion of Coatings

Except for temporary and protective coatings, all other types of surface coatings must adhere te-

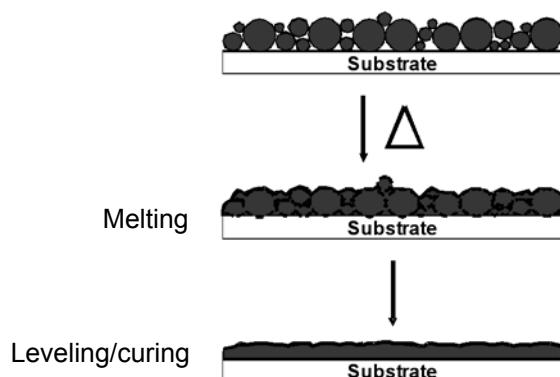


Figure 5-4. Fusion and crosslinking in powder coatings.

naciously to the substrates and preferably last as long as the object itself. Since coatings must function by surface attachment only, the nature and condition of the surface is critical to the success of any durable coating venture.

Both durability and performance of coatings, to a large extent, depends on cohesion and adhesion. Cohesion is associated with the strength of coating. That is, how tough, how elastic or how hard a coating is. Adhesion, on the other hand, is viewed as the strength of the bonds that the coating forms with a surface. These are two different and interrelated properties. Adhesion loss due to cracking is related to coating strength while “sheeting off” and delamination of a coating may be due to the lack of adhesion possibly as a result of poor surface preparation. The schematic representation of cohesion and adhesion as a function of weathering is shown in Figure 5-5.

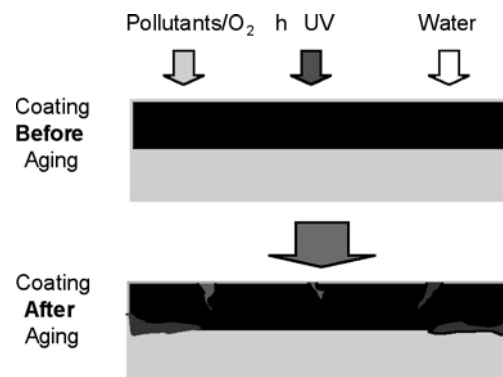


Figure 5-5. Adhesion and cohesion loss in a coating.

An important factor controlling this property is the balance between adhesion and cohesion. In general, the difficulty of removing the coating can be strongly affected by the roughness of the substrate. If the substrate has undercut areas that are filled with cured coating, a mechanical component makes removal of the coating even more difficult, analogous to holding two dovetailed pieces of wood together. However, greater surface roughness is only of advantage if the coating penetrates completely into all irregularities, cracks, and crevices of the surface. Failure to completely penetrate can lead to less coating to interface contact and will leave voids between the coating and the substrate, which can cause problems.

In order to obtain interaction between a coating and a substrate, it is necessary for the coating to wet the substrate. Simply, the surface tension of the coating must be lower than the surface tension

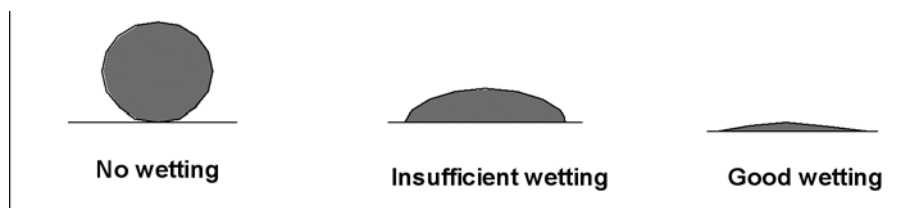


Figure 5-6. Schematic representation of wetting a surface by a liquid.

of the substrate. In the case of metal substrates, clean metal surfaces have very high surface tensions and any coating will wet a clean metal surface.

Wetting is the first step in securing a coating onto a surface. A complete wetting will allow the spread of coating over the entire surface of the substrate, permitting penetration through the imperfections and undercuts within the substrate. Schematics of wetting and its degrees are shown in Figure 5-6. The lack of wetting is demonstrated by a grey sphere contacting the surface at only one point (upper left). The complete wetting is indicated by the flat grey liquid. Subsequent to this, the coating cures or hardens while within the substrate, thereby securing the coating onto a surface.

Wetting is a function of surface free energy. The surface free energy simply is the energy difference between atoms on the very top surface of a substrate and the atoms in the bulk. The higher the surface energy, the better is wetting. Conversely, it is difficult to completely wet low surface energy substrates. Liquids generally bead up on low surface energy surfaces. This is analogous to water drops on a freshly washed and waxed car.

Wetting can be improved and enhanced in two ways. 1) By modifying the substrate surface. This can be accomplished by removing oils, and dirt etc. Once grease and other materials are removed, surfaces of most steel and aluminum substrates demonstrate high free energy which will allow good wetting. This method is discussed in more detail under the **Surface Preparation Methods**. 2) By reducing the surface tension of coating (or using low surface tension coatings). Among the coating materials, silicone coatings and those containing Teflon are the lowest surface tension coatings.

It is critical that the coating provides good adhesion to a metal surface by complete penetration into the surface irregularities of the metal substrate (Figure 5-7). This requires sufficiently low surface

tension to obtain wetting, but the degree of penetration is controlled by the viscosity of the continuous phase of the coating. Slowly evaporating solvents should be used in coatings to be applied directly over metal. Systems that cross-link slowly minimize the increase of viscosity of the continuous phase. Because viscosity of the vehicle drops with increasing temperature, baking coatings can be expected to provide better adhesion than a similar composition coating applied and cured at room temperature. This confirms that the observation that superior performance is obtained with high temperature baked, slow-cure primers when excellent adhesion is a critical requirement.

Adhesion is strongly affected by the interaction between coating and substrate. On a clean steel substrate containing some iron oxide, the formation of certain bonds between a coating binder and

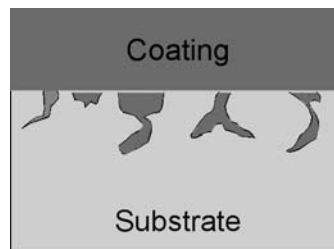


Figure 5-7. Mechanical adhesion.

the surface is very probable. There are several more theories of adhesion discussion of which is beyond the scope of this publication.

The adhesion of coating is also affected by the development of stresses as a result of shrinkage during drying of the film. For example, most fast dry lacquers lose solvents in a matter of minutes a substantial volume reduction occurs in the fraction of a second. This loss of volume supply the force needed to pull the film from the substrate. Hence, less external force must be applied to remove the film, and adhesion is poorer. Sometimes such stresses can be relieved by heating the coating to anneal it. Internal stresses can also result from

solvent loss from the film and other polymerization reactions, as well as changes in temperature. These stresses alone or in combination with internal stresses developed during film formation can affect coating durability, particularly adhesion.

Surface Engineering

Many of the most pressing issues the coatings industry faces today are related to surface preparation. The highest quality coating will show excellent results only if the surface pretreatment (cleaning and priming) is performed correctly and the overall system is maintained up to its potential.

Proper preparation of the metal surface prior to coating is one of the most important requirements for a successful finishing operation.

Without a good bond to the substrate no coating will perform satisfactorily. Adhesion is therefore a prime essential in all cases, not merely at the time of application but continuing indefinitely, and this can be assured only by proper surface preparation. It is entirely possible to produce, with a minimum of surface preparation, a painted metal surface which appears to have adequate adhesion before exposure to corrosive influences. Most organic coatings, however, are permeable to moisture and gases, and corrosion of the metal may occur under the organic film. Unless the surface has been properly prepared, such corrosion leads to the formation of metal salts and moisture pockets beneath the coating, causing premature failure of the protective coating by loss of adhesion.

Ideally, nothing should be allowed to come between the bare metal and the coating. Even the slightest deposit of ever present moisture from the atmosphere will play some role, depending upon circumstances, in determining the life of the coating. Careful shop coaters will even go so far as to heat the metal products prior to applying a coating, so that even the suspicion of moisture will be eliminated.

More obvious than moisture are surface contaminants such as dust, rust, mill scale (a complex bluish iron oxide that forms on steel in forging or forming processes), grease, oil, weld deposits, sweat or chemicals. These must all be removed if adhesion is to be adequate to keep corrosive materials away from the substrate and to permit

the corrosion fighting chemicals in the primer coat to perform their function.

Since coatings must function by surface attachment only, the nature and condition of the adherent surfaces is critical to the success of any coating venture. A rough surface provides more surface area than a smooth one of the same gross dimensions. In addition, the surface will usually have a chemical composition different from that of the bulk and in some cases the surface composition has little in common with the bulk composition either through adsorption of contaminants from the environment or from segregation of bulk constituents at the surface. The outer layers can be loosely bound or tightly adhered and might have high or low cohesive strength in themselves. Contaminant and segregated bulk components are not always homogeneously distributed in the surface region and inhomogeneities can lead to potential corrosion sites, weak bond areas, and bond discontinuities that can concentrate stress.

The “surface” of metals such as steel or aluminum alloys might consist of several regions having no clearly defined boundaries between them (Figure 5-8).



Figure 5-8. Schematic representation of a metal surface prior to surface preparation.

Moving outward from the bulk metal, there will likely be a region which is still metallic but which has a chemical composition different from the bulk due to the segregation of alloying elements, or impurities. Next, there will be a mixed oxide of the metals followed by the hydroxide and probably an absorbed water layer (Figure 5-9).

In addition, there will be contaminants absorbed from the atmosphere that might include sulfur, nitrogen, halogen or other compounds depending on the local air and rain pollutants and how the metal has been stored. There could also

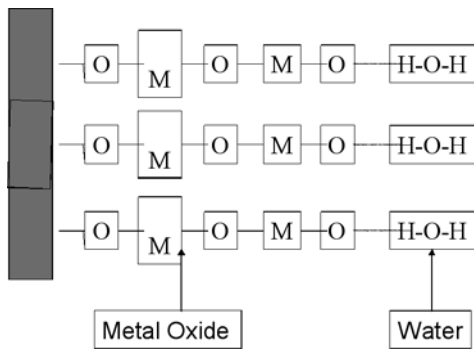


Figure 5-9. Schematic representation of a clean metal surface.

be processing aids such as rolling oils, cutting lubricants, drawing compounds and corrosion inhibitors. Finally, the mechanical working of the metal will probably have, to some degree, mixed all these regions together into something for a non-homogeneous “surface frosting”.

Choosing surface treatments and primers is as important to success as choice of coating. All must be considered at once since success depends on their proper interaction. Surface treatments are operations that change the morphology or composition of the substrate surface and may involve adding as well as removing or rearranging material. Primers are usually thin organic coatings applied to the surface (which might also have been treated) to give a more reproducible and durable surface for the coating. In all cases, the major reason for treating or priming is not necessarily to improve the adhesion but rather to produce a controlled, reproducible and durable surface in order to obtain a more predictable coating.

The cheapest and least controlled is to simply accept whatever surface is present and make no attempt to change it. This can be entirely adequate in many constructions. Solvent wiping can remove many organic contaminants but requires ventilation and that the solvent be changed as needed to avoid redepositing contaminants (the “steady state” situation). Mechanical abrasion, such as sanding or shot blasting, is effective where the substrate is sturdy enough. Abrasion usually leaves abrasive residue embedded in the surface and the fresh surface of many materials can be quite reactive so that it changes rapidly on exposure to air or to cleaning solvents. Chemical stripping or acid etching removes the outer layers and replaces them with a more controlled layer, but as with solvent cleaning, there is the danger of redeposition or

poor stripping if the enchants are not kept clean and at the proper concentrations. Etching followed by deliberate deposition of a controlled surface can provide the most reproducible surface but at the greatest expense. Physical deposition such as treatment of steel with zinc to produce galvanized surface is an excellent way. Chemical deposition of the new surface, such as in chrome conversion coating or zinc phosphate treatment, has been used for many years where long life and durability of metal constructions are important.

The processes commonly used for cleaning and conditioning the surface vary somewhat with the different metals and coatings, but they may generally be classified as follows:

1. Chemical treatments: Pickling, or acid cleaning (SSPCSP8) alkali cleaning, conversion treatments.
2. Solvent cleaning and degreasing (SSPC-SP1).
3. Mechanical cleaning: hand cleaning (SSPCSP2); power tool cleaning (SSPCSP3)l abrasive or shot blasting (SSPCSP5, SP6, SP7, SP10)1 flame cleaning, steam cleaning.

The first two methods listed, chemical and solvent cleaning, are used for all of the metals. The term “pickling” is used in the iron and steel industry and the term “acid cleaning” in the nonferrous metal trades. All of the typical processes have been described in some detail in the discussions of chemical finishes and treatments, as applied to the various metals, in Chapters 1, 2, 3, and 4. The use of mechanical methods for cleaning is largely confined to carbon steel and iron, and they have therefore been discussed in connection with finishes for those metals in Chapter 4.

Frequently pretreatments are applied after cleaning to serve either as passivators of the metal or to provide a better bond for primers that may otherwise not be sufficiently adherent to the metal surface. Phosphates, chromates and other chemicals used in pretreatments discourage corrosion by making the metal passive to electrical flow that may be set up if moisture reaches the surface. A vinyl wash primer is spread, like the passivators, in films of fractional mil thickness to bind the primer to surfaces to which it would not otherwise adhere.



Figure 5-10. Mechanical adhesion as a result of surface roughness.

Surface roughness affects adhesion in two ways 1) through surface roughening one is actually increasing the surface area where coating contacts the surface. The larger the contact area the harder it is to remove a coating. Therefore, the difficulty of removing a coating can be increased by increasing the surface area. 2) By providing surface irregularities, pores, holes and crevices into which the coating solidifies. In this manner the coating, much like a nail in a wood assembly, acts as a mechanical anchor. Therefore, if the substrate has undercut areas that are filled with solidified and hard coating, a mechanical component makes removal of the coating more difficult, analogous to holding two dovetailed pieces of wood together. Iron or zinc phosphate coatings provide larger contact areas and thus enhance adhesion and corrosion resistance. Figure 5-10 illustrates a hypothetical profile of a substrate profile.

Mechanical Cleaning

The mechanical, abrasive method is suitable where steel surfaces exhibit severe corrosion, loosely adherent heat scale, or numerous weldments and where soils have been carbonized in and around the exposed weldment area. These

types of surface contaminants make it very difficult to achieve any form of quality adhesion.

Chemical cleaning alone, even a five stage system probably will not produce a clean enough surface if parts exhibit the characteristics listed above.

Three Types of Mechanical Surface Preparation:

1) Air/Media Blast: The most common type generally referred to as sandblasting is a combination of compressed air and media. Problems associated with employee safety, referred to as “silicosis” has altered wide spread use in open air environments. A specially designed cabinet or enclosed area, along with air induced breathing apparatus, has insured continuing growth of this method of mechanical surface preparation.

2) Water/Media Blast: This method is gaining popularity because of the reduction of silicosis associated problems. Wet spot blasting of weldments has become accepted because of these reasons: (a) during the welding process, oily soils are carbonized, creating an impossible cleaning condition through a three or five stage washer. (b)

Optimum Process for Mechanical Cleaning

Normal Process

1. Blast
2. Clean and phosphate
3. Rinse
4. Seal rinse
5. Dry
6. Coating

Optimum Process

1. Chemically degreased
2. Rinse
3. Dry
4. Blast
5. Alkaline clean
6. Rinse
7. Phosphate
8. Rinse
9. Seal Rinse
10. Dry off
11. Coating

The surface of weldments is basically inert to the development of a conversion coating because of the scale developed. Wet spot blasting units are relatively inexpensive, low in labor requirements, and prove to provide the best possible substrate conditions prior to phosphatizing.

3) Centrifugal Wheel (Airless): This airless process is quite popular for larger, heavier-bodied parts where rust and scale must be removed. Centrifugal wheel is most often done in an enclosed cabinetry operation. The media is normally steel shot of varying sizes, depending on the substrate profile required.

Chemical Cleaning: The highest quality coating will show excellent results ONLY if the pretreatment (cleaning and phosphating) is done correctly, and the overall system is maintained up

to its maximum potential.

Chemical pretreatment, primarily iron phosphating, is the most widely used pretreatment prior to coating. In this process a thin layer of phosphate coating is deposited onto steel substrates. Because the coating is an integral part of the steel, it is usually highly adherent which provides an excellent base for coating adhesion. The simplest operation can require about 5-15 minutes. The thin phosphate coating is smooth to touch, however, on a molecular level it provides larger surface area of adhesion. A close up picture of a typical phosphated steel surface is shown in Figure 5-11.

Corrosion Control

Rusting, the oxidation of iron and steel to iron oxides, is the most common form of corrosion and

Dip Tank Application Methods

Dip Tanks - Best suited for large volumes of small parts.

3 Stage Dip -	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
	Clean & Phosphate	Rinse	Seal Rinse	-----	-----
5 Stage Dip -	Alkaline Clean	Rinse	Phosphatize	Rinse	Seal/Rinse

Time: 3 - 15 minutes
Temperature: 160 - 180°F
Concentration: 6 - 15% volume

Advantages

Low cost process equipment will handle volume of small parts.

Good for multi-configured parts not likely to receive good spray coverage.

Disadvantages

Need 5 stage for best results.
Cleaning with impingement is difficult (smut).
High chemical concentrations require high heat.

Iron Phosphating

Purpose - Promote adhesion of coatings, prevent corrosion, and maximize life of coatings.

Iron Phosphating - The development of an amorphous coating on iron bearing metals.

Process - 1 stage, 3 stage, 5 stage

Time: 60 seconds, 90 seconds for spray

3 - 5 minutes for dip

Temp: Ambient to 160°F (60-70°C)

20-60 mg/sq. ft. (20-60 mg/900 cm²)

Advantages

Low cost
Wide parameters
Application easy to maintain
Disposal not complicated
Industry standard for most coatings

Disadvantages

Less corrosion protection
than zinc phosphate

Line speed requires planning.

Zinc Phosphating

Purpose - Promote adhesion. Increase corrosion protection.

Zinc phosphating - Microcrystalline formation.

Primary metals - Ferrous (iron bearing)

Aluminum and zinc bearing

Process - 5 stage minimum, typically 7 stage.

Time: 60 - 90 seconds spray

3 - 5 minutes dip

Temp: 140 - 160°F (60 - 70 °C)

150 - 300 mg/sq. ft. (150 - 300 mg/cm²)

Advantages

Increase corrosion protection

Disadvantages

More costly
Greater process Equipment
Zinc effluent treatment
Greater control required

Seal Rinse Advantages/Disadvantages

Non-Chrome

Advantages

No disposal problems
Good adhesion
Removes unreacted phosphate

Disadvantages

Less tolerance to hard H₂O
Daily dumping and recharge
Less salt spray hours
Requires D.I. water

the most obvious one (Figure 5-12). The good news about rust for the coating industry is that paint can be used to control it. The bad news is that it is not really totally preventable. However, in many cases, through good manufacturing processes one can delay corrosion for long periods of time.

Corrosion is an electrochemically driven process of energy exchange. In this process, the metal, which was originally found in nature as an ore, is reconverted back to its ore. In the metallic

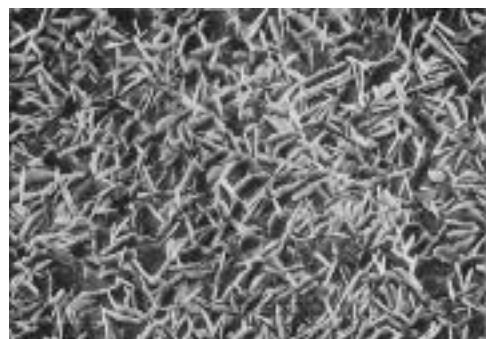


Figure 5-11. Photo-micrograph of phosphated steel.

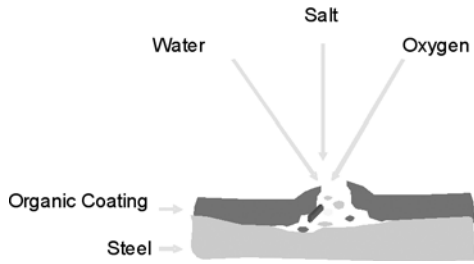


Figure 5-12. Cross section of a corrosion site.

state, the metal is in a higher energy state than it was when combined with other elements as an ore. That is, corrosion is a naturally occurring phenomenon. In short, metals corrode because they need to return to their original form.

Corrosion has four components. The metal (part of it) that corrodes (anode); the metal (part of it or another metal such as weld material) that causes corrosion (cathode); some sort of electrical connection; and a conductive media such as salt water (electrolyte). The first three requirements are always present in a fabricated metal work piece- such as steel and weld material and the connection. However, dry salt alone without two other reagents cannot cause corrosion. The other two reagents are water (moisture) and oxygen. The three reagents, salt (ions, electrolyte); water, and oxygen are called the Corrosion Triangle. For corrosion to happen all three must be present and at the right concentration. The schematic of corrosion triangle is shown in Figure 5-13.

Some metals corrode faster than the others. This tendency is also related to how much energy it takes during the smelting process to produce the metal. The more energy that must be imparted in the smelting process, the more readily the metal corrodes. In Figure 5-14, the most “active” metals are those that most readily release energy, and therefore, they are the ones most susceptible to corrosion.

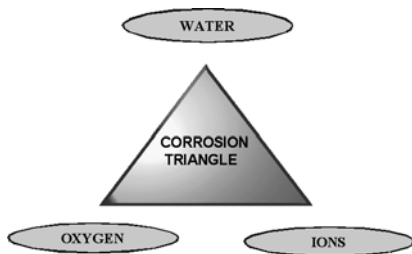


Figure 5-13. Chemical components of corrosion.

The surface of steel is not at all homogenous. Some areas are more active (are more prone to oxidation) than others and if there is scratch, pin-hole, or scribe, that area definitely will be more active. Weld metal often is more active than surrounding steel. Steel is more active than the mill scale that sometimes covers it (incompletely). These more active sites are where oxidation (corrosion) occurs.

Unlike many other metal oxides such as those of chromium, zinc, copper, and aluminum, rust does not stick tightly to iron and steel. In addition, it tends to pick up water from the air and is somewhat soluble in water. Therefore, rust tends to pull away from iron or steel so that new rust is

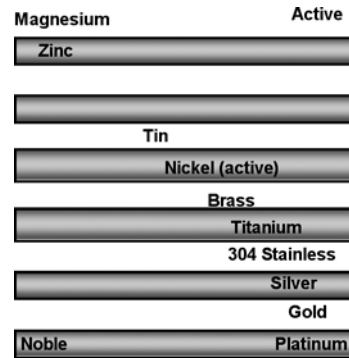


Figure 5-14. The most “active” metals are those that most readily release energy.

formed. The growing rust layer tends to push any paint away from the metal and also acts as weak boundary layer, particularly when water is present, so the coating may adhere poorly.

As the coating loses adhesion, salt solution moves into the gap and corrosion spreads further and further. After the coating falls off or is scrapped off, the effects of this process often are seen as a series of concentric circles around the original point of attack. These circles indicate (Figure 5-15) that the corrosion occurred as a series of stages rather than in a smooth, continuous process.

Corrosion has many types and shapes. While all types result in some type of damage, some are less dangerous than others. A few of the well known types are as follows:

- Flash rust
- Blistering
- Filiform corrosion
- Perforation corrosion

Stress corrosion
Cosmetic corrosion
Erosion corrosion
Pitting corrosion
Granular corrosion

Of the above, flash rust is the easiest one to deal with. Flash rust occurs when steel grit debris corrodes due to surface moisture. It can be easily prevented by surface treatment prior to priming or painting.

Blistering, which is the first sign of corrosion, generally is the result of poor adhesion. All organic coatings are permeable to water, oxygen, and various ions from the environment. If there is a marginal adhesion, water and ions can penetrate the coating and find their way to the metal surface. As the permeation and penetration process continues more water, ions, and soluble additives from the coating will collect beneath the coating. The trapped water and salts exert osmotic pressure. At some point, the forces generated by osmotic pressure displace the paint from the substrate and bends the coating film, thereby leading to the formation of a blister.

Osmotic pressures can be expected to range between 2,500 and 3,000 kPa while the resistance of organic coatings to deformational forces is much lower, ranging from 6-40 kPa. As the blister grows larger, the exposed area of unprotected steel surface increases, more corrosion products are formed, and the process proceeds still more rapidly. However, if the coating covers the whole surface and provides a tenacious adhesion, probability of water becoming in contact with a bare steel surface will be greatly decreased. Schematic representation of this process is shown in Figure 5-16.

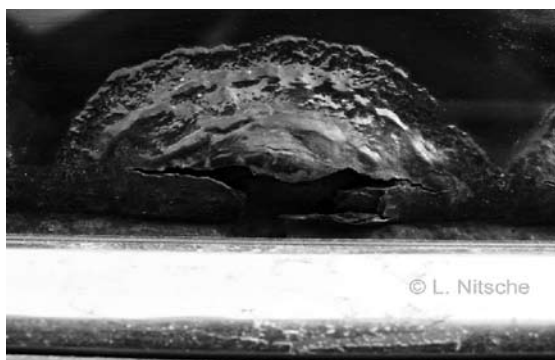


Figure 5-15. Corrosion of steel.

Techniques for Controlling Corrosion

Techniques for the control of corrosion are very diversified. The three basic types that can easily be employed are: Barrier protection (paint), inhibitive primer protection, and cathodic protection (sacrificial zinc-galvanized steel).

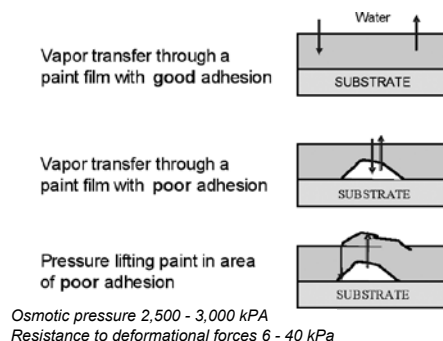


Figure 5-16. Schematic representation of blister formation mechanism.

Corrosion Prevention by Coatings

How can corrosion be prevented or reduced? A number of things can be done before objects are painted, better design, better quality substrates (galvanized steel, for example), better cleaning, and better pretreatment. Design is crucial. If an object traps water, electrolyte (salt) and dirt, corrosion will occur regardless of the quality of the preparation and paint. On the other hand, a good design, coupled with good cleaning, pretreatment, and painting should resist corrosion for a very long time. Closer cooperation between designers, pretreatment suppliers, painters, and paint manufacturers is needed. This is part of the total system concept. The whole "finish" must be developed with cooperation between all of the suppliers. The various components cannot be taken in isolation.

What is the part of the coating in this scenario? Consider the constituents of the corrosion site: the metal substrate, water, oxygen, and a salt solution. If any one of the latter three can be removed, corrosion will be prevented. Typical organic coatings have such high water permeabilities that water cannot be kept out. With oxygen, there will be enough present for corrosion except in the case of very thick (15 mil) maintenance coatings. Therefore, the only thing left for the coating is to prevent salt (ions, electrolyte, which penetrates the coating much slower than water or oxygen) from getting to the metal surface or greatly reduce the rate of penetration. If corrosion does begin, then

the job of the coating is to prevent or reduce the spread of corrosion.

The substrate is kept isolated from conductive electrolyte by the physical, insulating barrier of the crosslinked coating (more of a filter than a barrier), by the use of flat platy pigments such as mica-ceous iron oxide which provide another barrier.

Another approach is to use inhibitive primers that contain special inhibitive pigments that dissolve in water. Unlike the ions of corrosive salt, these materials react with the substrate to form protective films that further protect steel from corrosion.

A somewhat different technique is to alter the nature of the very top surface of the substrate. One way to prevent or reduce corrosion is to use a material that is sacrificial, i.e., it dissolves instead of the iron or steel. Galvanized steel has a zinc coating that plays this part. The zinc becomes the anode (a larger one) and slowly dissolves, but the steel (the cathode) does not. In addition, the zinc corrosion products are more stable, passivating, and adherent than is rust. They are relatively impermeable, block pores in the coating, and generally provide a protective barrier. A variation of this method exists in which a powdered zinc is incorporated into a coating formulation. The sacrificial material used in organic coatings is zinc dust (90-95 % of the total weight of the dry coating). Metal contact between the steel and the zinc particles is essential in the early stages of the exposure, but due to the corrosion products, good protection is provided even after the contact has been lost.

Even with well-formulated coatings containing effective corrosion inhibitors, damage can occur to the cured film that allows corrosion to begin. In such a case, it is crucial for the coating to have the ability to resist the spread of corrosion. To do this a coating must have adhesion, especially good wet adhesion, and be resistant to alkaline corrosion products. If the coating cannot be lifted or dissolved, then it will be very difficult for the salt solution to travel along the metal/coating interface and widen the corrosion front. Unfortunately, poor surface preparation and pretreatments with poor alkali resistance can negate the effects of a good coating and allow corrosion to spread.

Metallic Coatings

Steel sheet is a very versatile product. Unfor-

tunately, steel sheet is prone to rusting, a phenomenon that causes the surface to become unsightly and, over time, may contribute to product failure. For this reason, steel has been protected by a variety of methods ranging from internal alloying (stainless steel, for example), to coating with paints or metallic coatings.

Galvanized coatings and other metallic coatings on steel sheet provide good, long-term protection from corrosion. One can obtain many years of corrosion protection through the proper use of the metallic coatings available in today's market. Nevertheless, the application of high quality paint can add substantially to the overall life of coated steel sheet products. A classic example of the improvement in product life that a good paint system can provide is the enhancement achieved with automotive-body steels. The metallic coating on automotive body panels is quite thin compared with the metallic coating thickness on sheet panels used for many other types of applications, but with the synergistic effect of the paint systems used by the automotive industry, the life of the body panels is very long.

Metallic coatings can protect steel in two ways:

1. Like paint, they provide **barrier protection**, and
2. In many instances, they provide **galvanic protection**.

Each of these types of protection is described below.

Barrier Protection

The main mechanism by which galvanized coatings protect steel is by providing an impervious barrier that does not allow moisture to contact the steel - without moisture (the electrolyte) there is no corrosion. The nature of the galvanizing process ensures that the metallic zinc coating has excellent coating adhesion, abrasion, and corrosion resistance.

Galvanized coatings will not degrade over time as with other barrier coatings, such as paint. However, zinc is a reactive material and will corrode and erode slowly. For this reason, the protection offered by galvanized coatings is proportional to the coating thickness. The ability of a zinc coating to protect steel by acting as a barrier depends on zinc's corrosion rate. It is therefore important to

understand zinc's corrosion mechanism and what factors affect its corrosion rate.

Freshly exposed galvanized steel reacts with the surrounding atmosphere to form a series of zinc corrosion products. In air, newly exposed zinc reacts with oxygen to form a very thin zinc oxide layer. When moisture is present, zinc reacts with water and carbon dioxide resulting in the formation of zinc carbonate. Zinc carbonate is a thin, tenacious, and stable (insoluble in water) layer that provides protection to the underlying zinc, and results in its low corrosion rate in most environments.

The second shielding mechanism is zinc's ability to galvanically protect steel. When base steel is exposed, such as at a cut edge or scratch, the steel is cathodically protected by the sacrificial corrosion of the zinc coating. In practice, this means that a zinc coating will not be undercut by rusting steel because the steel cannot corrode adjacent to the zinc coating. Any exposure of the underlying steel, because of severe coating damage or at a cut edge, will not result in corrosion of the steel and has minimal effect on the overall performance of the coating.

If the coating is consumed, why use it? In the case of a zinc coating, the rate of corrosion that it undergoes while protecting steel is considerably lower than that of the steel. In this way, a thin coating of zinc can be applied to steel to protect the steel for a long time. For example, in a rural atmosphere where the number and concentration of pollutants in the air is generally quite low, zinc might corrode at a rate of 1.0 m/year (0.04 mil/year) while low-carbon steel in this same environment might corrode at a rate 5 times as high (5 $\mu\text{m}/\text{year}$ or 0.2 mil/year) or even higher. A primary reason for the reduced rate of zinc corrosion versus the rate for steel is that, as it corrodes, it forms an adherent, protective oxide/carbonate film on its surface similar to the oxide film on the surface of aluminum. This film itself helps to prevent contact between the environment and fresh zinc. Thus, the rate of corrosion decreases. Recall that steel typically does not form a protective film in that the oxide layer spalls, thereby, constantly exposing fresh iron to the environment.

The film that forms on the surface of zinc is not as protective as the aluminum oxide film on the surface of metallic aluminum. That is, the oxide is susceptible to dissolution if the moisture is

sufficiently acidic, for example. This is good and bad. It is good in that, if the oxide film were totally protective, the zinc would no longer offer galvanic protection to the steel at exposed areas. Thus, rusting of steel would occur at scratches and other exposed areas. The downside of the somewhat incompleteness of protection of the oxide film on a galvanized sheet is that the coat itself corrodes and thus, has a defined life.

Among the commercially available metallic-coated steel sheet products, zinc (galvanize) offers the most galvanic protection. Galfan® behaves somewhat similarly with respect to the level of galvanic protection that it provides. Galvalume® steel sheet offers somewhat reduced galvanic protection versus a galvanized or Galfan® coating. What does this mean about the relative performance of these products?

As with most things in life, everything comes with a price. Galvanically protective coatings are consumed by corrosion eventually. That is why a galvanized sheet has a definite lifespan before the corrosion of the steel begins. Thus, the amount of zinc applied to the steel during manufacture, described as the coating weight (mass), is important to the life of the product. Coating weight (mass) is expressed as G60 (Z180), G90 (Z275), G200 (Z600) etc. per ASTM Specification A 653/A 653M. G60 (Z180) means that the coating weight (mass) is 0.60 oz/ft² (180 g/m²), minimum (total coating on both sides of the sheet). This coating weight (mass) can be translated into thickness; a G60 (Z180) coating of zinc is about 0.00055 in. (0.014 mm) per side of the sheet.

For a galvanized coating, the rate of corrosion of the coating is typically linear in most environments. That is, twice the coating thickness translates to twice the life. That is, a G60 has twice the thickness of a G30 coating and the life of the product (defined, perhaps, as the time to 10 percent rust) in a given environment is approximately twice as long. Similarly, a G90 coating is approximately 50 percent thicker than a G60 coating, and thus would be expected to perform 50 percent better (in terms of time to 10 percent rust). Of course, different environments are more or less corrosive than other sites, so that the "life" of the coating varies considerably for different "environment types".

When the salt spray test is used for testing metallic-coated steel sheet, the corrosion performance is rated in the following ways:

- Number of hours until rusting of the steel is first evident,
- Number of hours until 5% of the surface area is rusted,
- Number of hours until 10% of the surface area is rusted, etc.

The onset of red rust on a sample of galvanized sheet, for example, means that the coating has been consumed by the corrosion reaction, and the corrosion of the base steel is beginning. There is no one best performance criterion. It simply depends on what the user defines as failure. The following table is one guideline that can be used as a measure of expected performance of three zinc-containing hot-dip coatings.

Coating Galvanized Steel

The main mechanisms by which galvanized coatings protect steel are:

- 1) By providing an impervious barrier that does not allow moisture to contact the steel - without moisture (the electrolyte) there is no corrosion.
- 2) By acting as an anode and sacrificially corroding thereby protecting the steel substrate.

Zinc is a reactive material and will corrode and erode slowly while protecting the steel substrate. For this reason, the protection offered by galvanized coatings is proportional to the coating thickness. While in theory by increasing the zinc coating thickness substantial corrosion resistance can be obtained, in practice, mostly due to process and economical reasons, it provides a limited value.

In general, the application of high quality paint can add substantially to the overall life of zinc coated steel sheet products. The reason for improved corrosion resistance is as follows:

In situations where the accumulations of zinc corrosion products build up over the surface, the effective anode area will inevitably be reduced. In this case, while the barrier properties of the film may improve, the cathodic protection of newly exposed steel at nicks and abrasions will be diminished. A similar situation arises when abrasions and scratches occur. In this case, the area of active zinc available for cathodic protection may be limited to merely the edges of the zinc film at the immediate site of the scratch and is insufficient to protect the area of the steel exposed.

In addition, where the pH of the environment is outside of the 5.5-9.5 range (acid rain or heavily industrial and cattle spaces), acidic and alkaline constituents of the environment may attack and dissolve the polarizing barrier film of zinc corrosion products and the zinc anode itself. The anode will be consumed more rapidly, with its eventual destruction and consequent breakdown of the steel for lack of the protective anode.

Primer Coat

On carbon steel or iron, the application of a rust inhibiting primer is an essential step in the finishing process. Aside from inhibiting corrosion and helping to seal the surface, this first coat must also contribute to the adhesion of subsequent coatings. To accomplish the above functions, the primer itself must adhere tenaciously, be rather imperme-

Table 5-1: Guideline to Salt Spray Resistance of Zinc Containing Hot-Dip Coatings

Product	Approximate Time to 5% Red Rust (per micron [μm] of coating thickness)
Galvanize (zinc-coated)	10 hours ¹
Galfan® (zinc-5% aluminum alloy-coated)	25 hours ²
Galvalume® (55% aluminum-zinc alloy-coated)	50 hours ³

®Galfan is a trademark of the Galfan Technology Centre, Inc. ®Galvalume is a registered trademark of BIEC International, Inc.

¹Galvanize Z275 – typical coating thickness/side is 20.5 μm , so approximate time to 5% red rust is 205 hours in salt spray.

²Galfan ZGF275 – typical coating thickness/side is 21.5 μm , so approximate time to 5% red rust is 540 hours in salt spray.

³Galvalume AZ50 – typical coating thickness/side is 21.5 μm , so approximate time to 5% red rust is 1075 hours in salt spray.

able to the elements and agents of weather and the topcoat inhibit corrosion by various mechanisms. The primer should be formulated in such a way that none of its components will be softened or attacked by the high resin content and solvent of enamels used over them. "Enamel holdout" is a required characteristic of such primers.

A hot rolled mill finish is usually a satisfactory surface for receiving prime coats, if it is free of rust and loose scale. Tight blue mill scale on such surfaces need not be removed if they are primed soon after manufacture, and if the intended use is for interior work where there will not be high humidity. But if the steel has been exposed to the atmosphere for only a few days, sufficient invisible rust will usually be present to require the removal of mill scale regardless of the intended use of the end product. Rust pitting is never acceptable on metal to be used for architectural iron work. Cold rolled surfaces are likely to be oily and should be properly cleaned. If they are extremely smooth, phosphatizing or some form of abrading, such as mechanical steel brushing, will usually insure satisfactory primer adhesion.

The most successful corrosion-inhibiting primer coats usually contain pigments that are compounds of zinc, chromium or molybdenum with oxidizing, ionizing or sacrificial action. Those used in organic coatings include zinc oxide, zinc phosphate, zinc dust and calcium, zinc or strontium molybdate.

For use on aluminum, primers usually contain chromate pigments. Vinyl wash primers can be used in place of conversion coatings except on intricate assemblies, but for exterior use should be followed by a chromate primer. Primers containing lead, mercury or copper should not be used on aluminum.

Primer Vehicles

The vehicles or binders commonly used for primer coats on carbon steel and iron are the following:

Epoxy: Excellent adhesion over carefully prepared surfaces is provided by epoxies. They are resistant to impact, moisture and chemicals. For high performance, epoxies combined with polyamide resins are used with lead pigments or zinc dust. With zinc dust, epoxy primers also permit welding of the protected surface. Epoxy esters, made with a fatty acid, are used for less demanding conditions. (See SSPC PS 13.01).

Phenolics: With basic silica lead chromate or zinc chromate, phenolics provide good protection when exposure to excessive dampness or water immersion is likely to occur. A phenolic with red lead is also used (See TTP86, Type IV).

Alkyds: Usable with most corrosion-inhibiting pigments, alkyds serve as binders for moderately priced, readily adherent primers of intermediate durability, where meticulous surface preparation is not practicable. (See SSPC PS 2.00)

Acrylics: In both waterborne and solvent-thinned versions, the acrylics have proven successful for coil coatings and other finishes. Waterborne versions are used for maintenance primers where conditions permit only water blasting, acrylics can be applied over moist surfaces. Hardness, flexibility, and water resistance are good.

Polyesters: These provide impact resistance, hardness, solvent resistance and gloss retention with oven curing.

Vinyls: Recently developed high-build vinyl primers with iron oxide or zinc chromate provide excellent chemical resistance with less application effort than older types of vinyl, which are excellent except for their extremely limited film build. (See SSPC PS 4.00)

Silicates: Ethyl silicate and other silicates with zinc dust constitute outstanding primers under extremes of weather and salt and chemical exposure. (See SSPC PS 12.00).

Chlorinated rubber: Excellent resistance to moisture vapor transmission and to acids, alkalis and various salts characterize coatings based on chlorinated rubber.

Oils: These are often added to other vehicles to penetrate rust and promote adhesion. Some linseed oil, often combined with alkyds, is used with red lead. Where only the poorest preparation can be given to rusted surfaces, straight red lead in oil is used. (See TTP86, Type 1 and SSPC Paint System 1.00)

Intermediate Coats

Metal fabricators are usually required to apply a shop coat primer, with the intermediate and

final coats generally being applied in the field by the painting contractor. With increasing frequency, however, specifications are calling for complete coating in the shop before delivery, to reduce costs and obtain what is generally regarded as a better job, avoiding the problems of moist field conditions, uncertain temperatures, dust and other enemies of good coating performance. In such specifications, field touchup is required, to correct any damage received in transit.

Depending on the film build desired and the resinous binder used, one or more intermediate coats may be needed between the primer and the final topcoat. To get a 7 mil film for a difficult environment, one epoxy coat may be sufficient, but to get the same film build with a conventional vinyl, as many as four coats and a primer may be required. When lesser film builds are adequate, a single epoxy, urethane, or alkyd topcoat may be sufficient.

A first intermediate coat should have essentially the same properties as the primer. Frequently it is the same paint with a tinted hiding pigment to insure complete coverage. A second intermediate coat, when used, should be the same as the topcoat or midway in properties between the primer and the topcoat. A slight color difference is preferred, to insure that any voids in the topcoat will be apparent.

Current primer technology has, in many cases, eliminated the need for intermediate coats with most inorganic zinc, organic zinc, and epoxy polyamide primers. This is significant because of the saving in labor costs.

Factory Applied Finishes

Until recently, factory applied metal finishes were almost exclusively solvent-reducible. Now, however, Federal and local regulatory agencies in some states limit the amount and types of solvent that may be released into the atmosphere. Consequently, water reducible, powder and high-solids finishes are replacing a growing number of solvent-reduced materials and there is little doubt that this trend will continue for some time. It appears, though, that many solvent-reduced products cannot readily be replaced, and it is likely that with suitable changes in solvent content they will continue to be used.

Water-reducible acrylics, alkyds, polyesters, siliconized polyesters, modified urethanes and fluorocarbons, are growing in importance as factory applied finishes. High-solids coatings, requir-

ing little solvent, have also been gaining in usage, some of them being cured by ultraviolet or electron beam radiation. Powder coating for architectural metal products is also successfully being used.

Architectural metal coatings applied at the factory on both ferrous and nonferrous metals may be either clear or pigmented. Clear lacquers are often used as short-term protective coatings for aluminum and the copper alloys, but are not recommended for stainless steel. Many clear finishes degrade on exterior exposure because the sun's ultraviolet rays gradually affect their molecules. Clear acrylics, however, have long been recognized for their ability to withstand UV radiation. Also, some costly aliphatic urethane binders, developed for aircraft and space vehicles, have demonstrated outstanding UV resistance. The less resistant clears can somewhat be improved by addition of UV absorbers.

Pigmented coatings are affected less by UV light than the clears, because pigments to some degree screen or absorb them. Zinc oxide is particularly effective as a UV absorber. Because they yellow and chalk under UV exposure, epoxies, phenolics and some alkyds and urethanes are not normally selected for white and pastel colors on exteriors, although alkyds are satisfactory when their vegetable fatty acid components are derived from soybean oil, safflower oil or other suitable drying oils.

Factory applied finishes fall into two categories with respect to curing method: those that are air-dried and those that are force dried or baked. Binders used with either type may harden by oxidation or other chemical reactions, or by physical steps made possible by application. The latter include evaporation of the solvents in the applied coating, if the material is a lacquer, or the coalescence of binder particles if a latex emulsion, such as an acrylic, is used.

Factory applied finishes are mainly enamels. This means that they have a high proportion of resin and usually form hard, resistant finishes. Some enamel binders are thermosetting and require heat to harden them; others are heated only to hasten reaction with oxygen, or to hasten polymerization of the combination of certain chemical constituents. Some lacquers are heated to speed evaporation of the solvents and thus the drying of the film.

High performance exterior metal finishes, factory applied and heat-treated, have been rap-

idly growing in importance over the past decade. These virtually qualify as super coatings, some of them being guaranteed for as long as 15 years of service. Included among these are coatings based on fluorocarbons, silicone acrylics, silicone polyesters, and vinyl plastisols. These coatings are gaining wide acceptance as finishes on both aluminum and steel, for such products as industrial wall panels, metal curtain wall, and windows, in moderate to severe chemical environments. They are not to be confused, however, with the so-called "high performance architectural coatings" (HIPAC), which are field applied and air-dried products usually based on epoxies, silicone alkyds, urethanes or other excellent binders. These, with very limited exceptions, do not approach the performance of the factory applied and oven-treated super coatings.

Coatings chemists have become highly skilled in tailoring the factory applied finishes to provide specific properties. Nevertheless, the improvement of a given property can often be accomplished only at the expense of lower performance in respect to some other property. The dominant challenge will usually determine which properties will be emphasized, and in many instances some compromises are necessary. It is important, therefore, that the specifier recognize which properties are most essential for a specific application and select the combination of coating properties that will provide optimum overall performance.

Assume, for example, that a client desires a light colored high performance exterior coating. The coating preferred may be based on a binder which, though highly durable, is known to fade and lightly chalk. If white is mandatory, a somewhat less durable but nonyellowing and nonchalking coating may have to be selected. Or a binder with maximum impact resistance may be indicated, but the best binder for this purpose may offer inferior solvent resistance, and this may be a consideration of such importance as to require a compromise on impact demands.

In the following discussion of the various binders used in factory applied finishes and in the accompanying chart, **generalizations rather than specific recommendations are presented. Performance properties and costs are necessarily stated in relative terms.** This information is intended to provide reliable basic data for the specifier in respect to the various coatings and their general uses, *but final selections should be*

made only after consultation with representatives of reliable manufacturers.

Acrylic Resins: Acrylics have many valuable properties, notably their color and gloss retention and exterior weathering, both as clears and pigmented. While they are many higher performing resins available today, the price per function favors the use of acrylics as a coating. Premium quality acrylics, medium in price, have performed satisfactorily in many industrial atmospheres for more than a decade. They are suitable for use as a topcoat over epoxies, organic zinc primers, chlorinated rubber and some alkyd primers. Acrylics are available. Aside from the widely used emulsions, they are available as solvent-reducible thermosetting and thermoplastic metal finishes, and their use as water-reducible metal finishes for many purposes is steadily growing. Acrylic organosols and powder coatings are also available.

Alkyd Resins: These resins, in the past, have been the workhorses of the coatings industry because of their adhesion, flexibility, hardness, and general serviceability. Their low cost has made them attractive, in spite of their relatively limited service life and the tendency of some types to yellow in outdoor exposure. In recent years, however, the newer but proven materials such as acrylics and polyvinyl acetate emulsions in the moderate price range of products, and the high performance synthetics such as epoxy, urethane, chlorinated rubber, and vinyl resins, have been replacing them.

Alkyds, which are closely related to polyester resins, can be modified with styrene, silicone, or acrylic resins to overcome some shortcomings and to change the characteristics of the resins. The addition of urea or melamine resins to thermosetting alkyd formulations speeds cure from one hour to seconds, and improves gloss, chemical and solvent resistance, and durability. Alkyds are also used to modify cellulosic lacquers. Alkyd resins in general are susceptible for degradation through hydrolysis over time, yellowing hardening and chalking. Unmodified alkyds can function satisfactorily in indoor applications.

Cellulosic Resins: The types of cellulosic that are used as principal resins in lacquers require the addition of plasticizers or resins such as alkyds,

phenols or urea formaldehyde to improve both adhesion, and tensile strength. The three such types are:

- a. Nitrocellulose (cellulose nitrate), which is flammable and discolours with aging. It is compatible with many plasticizers and other resins and is generally modified with alkyd resins.
- b. Cellulose acetate, which has low flammability but otherwise has most of the limitations of nitrocellulose plus poor compatibility with most plasticizers and resins.
- c. Cellulose acetate butyrate, which, when modified with an acrylic, yields a coating with exceptional hardness, adhesion, and nonyellowing properties.

Two other cellulose are interesting because of their unique applications. Ethylcellulose is dissolved at high temperature in solvent blends that cannot hold it at room temperature. It is returned to ambient temperature and becomes a gel prior to dipping hot objects which, when coated, take on a smooth, uniform film that dries to 15 to 30 mils. This is known as a form of gel coat.

The other cellulosic is methylcellulose, in which color particles are suspended and mixed with nitrocellulose or other lacquer materials with a second color, to make multicolor coatings.

Chlorinated Rubber: Coatings based on this resin are used for special purposes, mainly to resist attack by microorganisms; where low permeability to water and water vapor is needed” and where radioactive materials may have to be cleaned up.

Epoxy Resins: Epoxy resins are characterized by their adhesion, gloss, corrosion resistance, hardness, and overall durability. The most important of the several epoxy types are those cured by polyamide resins, which impart flexibility, durability, abrasion and impact resistance, and overall chemical resistance. They are one of the most important binders used in powder coatings.

Thermosetting epoxy acrylics are used where mar resistance, gloss and color retention and chemical resistance are required. Pigmented epoxies cured by amine resins are used in areas where corrosion and chemical resistance is needed. Some epoxies yield high-build, tile-like pigmented coatings capable of withstanding repeated scrubbing in sanitary areas such as hospitals, dairies

and chemical plants. Epoxy resins best function as primers.

Fluorocarbons: These are costly premium coatings, ranking high among the ultra high performance exterior coatings. They are available in a wide variety of colors, but only low to medium gloss. Because of their high resistance to ultraviolet rays, they are distinguished for color retention and excellent weatherability. They have high resistance also to abrasion, impact, chemical attack and dirt pickup, so are easy to maintain. To insure good adhesion, the use of an extremely thin film of epoxyzinc chromate or similar compatible primer is usually required.

Melamine Formaldehyde Resins: These are similar to urea formaldehydes, except that they are not as compatible with many resins. Their advantages are that they harden more rapidly, have better gloss and color retention and alkali resistance, and can be baked at lower temperatures. These resins are used primarily as modifiers.

Phenolic Resins: Combinations of phenol and formaldehyde with or without the addition of vegetable oils have outstanding resistance to alkalis, chemicals, and moisture. They adhere to metal, and some versions are suitable for baking enamels where light or pastel colors are not desired.

Polyester Resins: Polyesters are oil free alkyds with certain advantages in chemical reactivity. They have a wide range of durability and flexibility. Specially formulated polyesters with amine modification are available as water-reducible coatings; various others are used for high solids coatings, powder resins, gel coats, and radiation cured materials. With silicone modifications they serve as high performance exterior coatings.

Silicones: Silicone based coatings are characterized by exceptional resistance to heat and weather exposure. In recent years these properties have been imparted to other binders by silicone modification of organic polymers, Silicone alkyds improve the weathering and gloss retention of alkyds, and silicone modifications of acrylics, polyesters, epoxies and urethanes enhance their weathering and color retention properties. Two of the more widely used ultra high performance exterior coatings for metal are based on siliconized acrylics and siliconized polyesters. Both of these products have excellent color and gloss retention, chalking and erosion resistance, and durability un-

der prolonged outdoor exposure.

Urea Formaldehyde Resins: Added to alkyd resins these provide flexible, hard films with excellent color retention but poor impact resistance.

Urethane Resins: resins and coatings are available in a wide selection of types, ranging from those resembling alkyds, but with some advantages, to highly sophisticated products capable of withstanding exposure to weather, abrasion, scrubbing, solvents and impact. Some air dried versions perform like baked coatings. The newer types have overcome yellowing tendencies. Those derived from versions used for aircraft and space equipment are so hard and solvent resistant that graffiti can be removed from them with strong solvents without discernible damage to the surface.

Urethane coatings are available as one- or two-part solvent and water-reducibles, powder coatings, and as one part moisture cure version. The two components generally cure dry-to-touch in a few minutes at room or elevated temperature depending on their formulation. The two-part urethanes provide better durability, solvent resistance and toughness compared to air-dry urethanes.

These costly resins have outstanding chemical and stain resistance and toughness. The older formulations yellowed and chalked outdoors, but new color stable types have been developed. The moisture-cured versions can be formulated to cure within 30-60 minutes of application.

Vinyl Chloride Copolymers: Vinyl chlorides are combined with varying amounts of polyvinyl acetate for softening and flexibility. The resulting binders are tough, nonflammable and resistant to moisture, oils, salt water and chemicals. Pigmented versions have excellent durability. Factory applied vinyls include solutions, plastisols and organosols. The plastisols have been supplied commercially to the coil coating industry for more than a decade and have found wide use as a high performance exterior coating for building sheets and panels, even when used in corrosive environments.

Powder Coatings: Powder coatings use a wide variety of resins discussed above. Thermosetting powders are available in polyester, epoxy, phenolic, acrylic, silicone resins and their combinations. As such, they demonstrate similar properties to those of liquid resins. Thermoplastic powders include, polypropylene, nylon, fluorinated polymers, and vinyl chloride.

Field Applied Topcoats for Carbon Steel and Iron

The final coat in a system should provide satisfactory protection for the primer and intermediate coats in accord with the specific requirements. While impermeability to moisture is usually desirable in metal coatings, all are permeable to some degree. Impermeability generally is proportional to film thickness. Coatings having a film thickness of 2 mils or less are likely to be permeable, while high build systems up to 40 mils thickness result in long-term impermeability.

Color retention is as important for exterior topcoats as is weather resistance. Many topcoats suitable for wood and masonry may also be used on metal. There are also several high performance coatings the cost of which may justify their use only on metal. Suitable products for use as topcoats on iron and steel are quite numerous. The older solvent reduced paints, such as those based on alkyds and phenolics, still serve useful purposes, and the synthetic resin binders provide topcoats with a wide range of durability potential. These range from the water reducible coatings based on conventional acrylics, polyvinyl acetate or aminized polyesters, with moderate life cycles, to the ultra long term coatings based on epoxies, urethanes, vinyls, certain siliconized polymers, the newer acrylics and the fluorocarbons.

Where moderate durability and indoor applications are required, **alkyds** are considered satisfactory. For exterior application, when gloss retention is an important consideration, the silicone modified alkyds are often used. Special requirements or exposure conditions may require topcoats having higher performance values. **Coal tar epoxies**, for example, consisting of epoxies and bituminous asphalt, are used in heavy coats with suitable pigments where moisture is expected to be unusually severe and color retention is not important. (See SSPC PS 11.01). Where exposure to the sun's rays may cause a buildup of heat on the metal surface, as on siding and roofs, white or light colored coatings are preferred. Aluminum pigmented paints are appropriate for such applications.

A **phenolic** topcoat over a phenolic primer serves well in locations that are damp or subject to chemical fumes, but their tendency to yellow and chalk outdoors may be a problem. With aluminum pigments, however, they have proven very durable. **Chlorinated rubber** finishes serve as

good insulators against electrolytic action where dissimilar metals are in contact, and they have good acid and alkali resistance. **Vinyl** finishes offer outstanding resistance to acids and alkalis and perform well in salt environments, but most of them offer very thin film build per coat. The newer high build vinyls overcome this deficiency but exposures have not yet shown what sacrifices in performance may accompany improved film build and consequent labor saving.

Epoxy finishes are distinguished for their toughness and their acid and alkali resistance, but they tend to chalk and yellow outdoors. Some epoxies, chiefly those combined with polyamides and polyamines, cure at room temperatures but perform like oven baked coatings. These should not be confused with epoxy esters. Other types dry to a tile like hardness but, unlike tile, are seam free, permitting meticulous cleanup in sanitary areas.

Urethane, coatings are available in a wide selection of types, ranging from those resembling alkyds, but with some advantages, to highly sophisticated products capable of withstanding exposure to weather, abrasion, scrubbing, solvents, and impact. Some air dried versions perform like baked coatings. The newer types have overcome yellowing tendencies. Those derived from versions used for aircraft and space equipment are so hard and solvent resistant that graffiti can be removed from them with strong solvents without discernible damage to the surface.

Acrylics, in water reducible formulations for exterior applications, have excellent color and gloss retention and weather resistance. They are suitable for use over inorganic zinc primers, epoxies, chlorinated rubber, and some alkyd primers. Premium quality acrylics, medium in price, have performed satisfactorily in industrial atmospheres for more than a decade.

Application of Coatings

Organic coatings are applied to metals by a variety of methods, depending upon the type of coating and whether the application takes place in the field or in the factory. Field applied paints, varnishes (clear coatings) and lacquers may be applied by brush, roller, or spray gun. Factory applied finishes have traditionally been, and still are, applied by spray, but other methods are being increasingly used. These include flow coatings, curtain coating, roller coating (coil coating), electro-

deposition, and powder coating, among others.

Spray applications, widely used both in the factory and at the job site, are of several different types. The spray guns, all of which are designed to atomize the coating, may use either compressed air or other gas, or hydraulic pressure as the motive force, with various interchangeable nozzles and air caps for different kinds of coating. Thinning of the coating is often necessary, and only recommended types of thinners should be used.

Hot spray is a method which employs heat to thin the coating, instead of a thinner. Its advantages are faster application, ease of applying thicker coats, moderately improved drying time and reduction of overspray.

Airless spray utilizes hydraulic pressure, atomization being achieved by release of the pressure through a small orifice, along with some flash evaporation of solvents. Some units use a combination of heat and pressure. In general, this method has all the advantages of hot spray, plus the elimination of heating units and the minimization of overspray.

Electrostatic spraying uses the principal of electrostatically charging the paint particle sprayed so that it is attracted to the grounded object to be coated which is of opposite polarity. This phenomenon causes paint particles, which might normally have missed the work piece, to be attracted to it and even pulled around to the opposite side of the work piece from that being sprayed. Articles to be coated are conveyed through a spray zone where an electrostatic field is maintained. Transfer efficiencies with electrostatic spraying, i.e., the percent of the material sprayed which reaches the work piece, may often reach as high as 98 percent, effecting a significant reduction in paint usage compared to the usage experienced with conventional methods. Electrostatic application equipment is available in both manual and automatic types and in the form of air spray, airless spray or rotary disk or bell atomizers. Many states now recognize the use of electrostatic spray equipment as a compliance method in reduction of solvent emissions due to the greatly reduced volumes of coating material required in the production process.

Dipping is an old, simple, and relatively crude method of application, in which the object being coated is momentarily immersed in a coating bath. With the proper coating formula, this is an appropriate method for coating complex objects, provided

Table 5-2: REPRESENTATIVE ARCHITECTURAL USES AND

Binder Type	Typical Uses	Application		Cost	Outdoor Life (years)
		Shop	Field		
ACRYLICS – Solvent reducible Water reducible: air dried – baked –	Residential siding and similar products; nets and implements; clear topcoats	yes	no	M	5
		yes	yes	M	5
		yes	no	M	10-15
ALKYDS	Exterior primers and enamels	yes	yes	L-M	5-7
CELLULOSE ACETATE BUTYRATE	Decorative high gloss finishes	yes	no	M	2-3
CHLORINATED RUBBER	Corrosion-resistant paints; swimming pool coatings; protection of dissimilar metals	yes	yes	M	2-3
CHLOROSULFONATED POLYETHYLENE	Paints for piping, tanks, valves, etc.	yes	yes	H	15
EPOXY	Moisture- and alkali- resistant coatings; non-decorative interior uses requiring high chemical resistance	yes	yes	M	15+
FLUOROCARBONS	High performance exterior coatings; industrial siding; curtain walls	yes	yes	H	20
PHENOL FORMALDEHYDE	Chemical- and moisture- resistant coatings	yes	yes	M	10
POLYESTER	Cabinets and furniture; ceiling tile; piping Maintenance finishes for both interior and exterior applications	yes	yes	L-M	15
POLYVINYL CHLORIDE	Residential siding; rain-carrying equipment; metal wall tile; baseboard heating covers, etc. Plastics: industrial siding; curtain walls	yes	yes	L-M	5-10
SILICATES (inorganic)	Corrosion-inhibitive primers; solvent-resistant coatings	yes	yes	L-M	10-15
SILICON-MODIFIED POLYMERS	High performance exterior coatings; industrial siding; curtain walls	yes	yes	H-VH	10-15
URETHANE (aliphatic-cured)	Heavy duty coatings for stain, chemical, abrasion and corrosion resistance	yes	yes	M-H	10+

KEY: L = Low; M = Moderate; H = High; VH = Very High; NA = Not Applicable or Not Available; P = Poor; F = Fair

they are designed to permit adequate drainage.

Flow coating is closely related to dipping, and is appropriate for coating objects too large to dip. These are conveyed through a tunnel equipped with nozzles that deluge them, using fluid pressure only. Excess material is collected and pumped back again to the nozzle reservoir.

Curtain coating is a method of finishing flat objects or sheets, in which the item to be coated passes through and perpendicular to a freely falling “curtain,” or waterfall, of coating. The flow rate of the falling liquid and the linear speed of the substrate passing through the curtain are regulated to provide the desired thickness of coating. This

method may be used with low viscosity resins or solutions, suspensions, or resin emulsions.

Roller coating is a long established method, suitable only for flat stock, that is commonly used for continuously coating coiled sheet and strip.

The coating is applied by a roller that is continuously replenished with liquid, usually by a feed roller. The application may be either direct or reverse; that is, the application roller may rotate either in the direction of the passing stock or in the reverse direction. Reverseroll coating is more suited for critical work, as it permits independent adjustment of several variables affecting quality.

COMPARATIVE PROPERTIES OF COATINGS

Color Stable Exterior	Gloss Retention Exterior	Stain Resistance	Weather Resistance	Abrasion and Impact Resistance	Flexibility	Water-Reducible Available	Clear Available	Weldable as Primer
yes	VG	G	G	F-G	G		yes	yes*
yes	G	G	F-G	G	G	yes	yes	yes*
yes	G-E	G	G-E	G	G	yes	yes	yes*
no	G	F	F	F	F-G	yes	yes	yes*
yes	G	F	G	G	G	no	yes	no
yes	F	F	G	G	G	no	no	no
yes	NA	F	E	F-G	E	no	no	no
no	P	G	G-E	E	G	yes	yes	yes*
yes	E	E	E	E	G	no	yes	no
no	F	F	G-E	G-E	G	no	yes	yes*
some versions	G-E	G-E	G-E	G	G-E	yes	yes	yes
yes	G	F	G-E	G	G-E	yes	no	yes*
NA	NA	NA	NA	G	G	no	no	yes
yes	G-E	G	G-E	G-E	G	yes	no	no
some versions	E	G-E	G-E	G-E	E	yes	yes	yes*

G = Good; E = Excellent

* For light non-structural welding only

Electrodeposition is a method of coating metal objects by suspending them in a water bath containing resins, electrolytic stabilizers and pigments, so that the objects are virtually plated with resins and color by electrolytic deposition. Objects in the bath become either anode or cathode depending on the chemistry of coating, while the anode (cathode) is either the tank or some suitable object suspended in the tank. Suitable resins and pigments for this process were formerly limited mainly to water-soluble epoxies and alkyd modified phenolic resins and iron oxides, but progress has been made in extending the selection and color range of the resins.

Powder coatings are deposited on an object as finely divided solids consisting of resinous material, additives to aid performance, and colorants if desired. The object to be coated is electrically grounded if the powder is to be electrostatically sprayed, and may be heated before or after the powder is applied. A less frequently used procedure is the fluidized bed process, in which the object is heated and immersed in an enclosure in which the powder is "fluidized" by a gentle current of air.

Coalescence of the powder particles on the heated surfaces, in either method, leaves a smooth, hard coating.

Care and Maintenance of Painted Metals/General Considerations

Organic coatings do not normally show an appreciable amount of dirt accumulation. In many atmospheres, dirt and soil would not be detrimental to the coating, but cleaning and surface care may be desirable for the sake of appearance. In areas where heavy industrial deposits have dulled the surface where materials from construction processes have soiled the surface, or where cleaner has rundown from other surfaces, surface cleaning is desirable.

Climatic conditions affect the cleanliness of organic coatings. In some areas rainfall may be sufficient to keep exterior surfaces looking clean and bright. In areas of low rainfall or in heavily industrialized areas, periodic cleaning will be necessary. This is also true of foggy coastal regions with frequent cycles of condensation and drying which may cause a build up of atmospheric salts and dirt. In any climate, sheltered areas under overhangs may become soiled from lack of rain washing. Cleaning painted metal components in the exterior wall may be scheduled along with cleaning the glass.

If automatic wall cleaning equipment is to be used on a building, a test should be made early in the equipment design to ensure that the cleaning solutions and brushes, as well as the frequency of cleaning, will have no detrimental effect on the coating.

Cleaning Procedures

Painted surfaces should be cleaned as soon as possible after installation to remove construction soils and accumulated environmental soils. Ideally, a forceful water rinse from the top down should be employed before applying any cleaner. Some type of surface agitation helps. A low volume of water at moderate pressure is better than a high volume at low pressure. Rubbing the surface with soft brushes, sponges, or cloth during the rinsing also helps.

If a simple water rinse with brushing, sponging, or rubbing with a cloth is not sufficient to remove the soil, a mild detergent or mild soap will be necessary. Washing with a mild detergent or mild soap should be done by brushing or sponging with a uniform pressure, first horizontally, then vertically. Following the washing, the surfaces must be

thoroughly rinsed with clean water. If the cleaner has been permitted to dry, it may be necessary to sponge the surfaces while rinsing. Rinsed surfaces may be permitted to air dry or may be wiped dry with a chamois, squeegee, or lint free cloth.

Cleaner rundown should be minimized and those areas subject to rundown should be rinsed immediately, and as long as necessary, to lessen the probability of streaking. Cleaning chemicals must not be allowed to collect on surfaces, to puddle on horizontal surfaces, or to collect in joints and crevices. These surfaces, joints and crevices should be thoroughly flushed with water and dried.

Mild detergents and soaps which are safe for bare hands should be safe for coated metal. Stronger detergents, such as some dishwater detergents, should be carefully spot tested. Some of the latter would necessitate using rubber gloves and long handled brushes. Some mild cleaning solutions are available for automatic building washing machines.

Mild solvents such as mineral spirits may be used to remove grease, sealant, or caulking compounds. Stronger solvents or solvents containing cleaners may soften paints. To prevent damage to the finish, the coating manufacturer should be consulted and these types of solvent or emulsion cleaners should first be spot tested. Care should be taken to assure that no surface marring takes place in this manner since it could give an undesirable appearance at certain viewing angles. Cleaners of this type are usually applied and removed with a clean cloth. Remaining residue should be washed with mild soap and rinsed with water. Use solvent cleaners sparingly.

Since solvents may extract materials from sealants which could stain the painted surface or could prove harmful to sealants, their possible effects must be considered. Test a small area first.

If cleaning heavy tenacious surface soil or stubborn stains has been postponed, a more aggressive cleaner and technique may be required. Cleaner and technique should be matched to the soil and the painted finish. Some local manual cleaning may be needed at this point. Always follow the recommendations of the cleaner manufacturer as to proper cleaner and concentration. Test clean a small area first. Cleaners should not be used indiscriminately. Do not use excessive, abrasive rubbing since it may alter surface texture or

impart a bright “shine” to the surface.

Dried concrete spillage on the painted surface may be quite stubborn to remove. Special cleaners and/or vigorous rubbing with nonabrasive brushes or plastic scrapers may be necessary. Diluted solutions of Muriatic Acid (under 10 percent) may be effective in removing dried concrete stains and effective proprietary cleaners for concrete and mortar staining are available, however, a test area should be tried first and proper handling precautions must be exercised for safety reasons.

Mixing cleaners may not only be ineffective but also dangerous. For example, mixing chlorine containing materials such as bleaches, with other cleaning compounds containing ammonia, can produce poison gas. Always rinse the surface after removing heavy surface soil.

Summary of Cleaning Tips

- Overcleaning or excessive rubbing can do more harm than good.
- Strong solvents (MEK for example) or strong cleaner concentrations can cause damage to painted surfaces.
- Avoid abrasive cleaners. Do not use household cleaners that contain abrasives on painted surfaces.
- Abrasive materials such as steel wool, abrasive brushes, etc., can wear and harm finishes.
- Avoid drips and splashes. Remove rundowns as quickly as possible.
- Avoid temperature extremes. Heat accelerates

chemical reactions and may evaporate water from solution. Extremely low temperature may give poor cleaning results. Cleaning under adverse conditions may result in streaking or staining. Ideally, cleaning should be done in shade at moderate temperature.

- Do not substitute a heavy duty cleaner for a frequently used, mild cleaner.
- Do not scour painted surfaces.
- Never use paint removers, aggressive alkaline, acid, or abrasive cleaners. Do not use trisodium phosphate or highly alkaline or highly acid cleaners. Always do a test surface.
- Follow manufacturers recommendations for mixing and diluting cleaners.
- Never mix cleaners.
- To prevent marring, make sure cleaning sponges, cloth, etc., are grit free.
- “An ounce of prevention is worth a pound of cure.”
- In addition to the foregoing, consideration must be given to the effects rundown may have on shrubbery, personnel, equipment and other items located below. Such considerations may affect the timing in the cleaning schedule.

Inspection

It is suggested that the building owner or manager provide a qualified inspector to see that the cleaning operations are carried out in accordance with the recommended procedures.

References

For more detailed information on the subject of organic coatings and corrosion control by coatings the following references are suggested:

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Contributing & Referenced Organizations

LIST OF CONTRIBUTING AND REFERENCED ORGANIZATIONS

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The Aluminum Association (AA), 900 19th Street NW, Washington, DC 20006.

American Architectural Manufacturers Association (AAMA), 1540 East Dundee Road, Suite 310, Palatine, IL 60067-8321.

American Galvanizers Association (AGA), 12200 East Iliff Avenue, Suite 204, Aurora, CO 80014.

American Iron and Steel Institute (AISI), 1000 16th Street, NW, Washington, DC 20036.

American National Standards Institute (ANSI), 11 West 42nd Street, New York, NY 10036.

ASTM International (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

American Welding Society (AWS), 550

N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135.

Builders Hardware Manufacturers Association (BHMA), 355 Lexington Avenue, 17th Floor New York, NY 10017.

Copper Development Association (CDA), 260 Madison Avenue, New York, NY 10016.

Federation of Societies for Coatings Technology, 492 Norristown Rd., Blue Bell, PA 19422, www.coatingstech.org.

International Organization for Standardization (ISO) *Note: ANSI represents U.S. technical activities in this organization.*

National Association of Corrosion Engineers (NACE Intl), 1440 South Creek Dr., Houston, TX 77084, www.nace.org.

Porcelain Enamel Institute (PEI), 1911 North Fort Meyer Drive, Arlington, VA 22209.

Powder Coating Institute, 2121 Eisenhower Ave., Suite 401, Alexandria, VA 22314.

Steel Structures Painting Council (SSPC), 4400 5th Avenue, Pittsburgh, PA 15213.

Zinc Institute (ZI), c/o Zinc Institute Archives, Held by Special Collections, Linderman Library,

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Notes

Notes

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