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HANDBOOK OF  
PLASTIC  
MATERIALS  
AND  
TECHNOLOGY

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Editor

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# 117

## ADHESION AND SOLVENT BONDING

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Industrial practice often requires that plastic parts be affixed to other plastics or to nonplastic materials. Of the methods available to engineers who must make judgements relative to the most suitable assembly technique, adhesive bonding must be seriously considered.

\* Adhesive bonding of plastic substrates is already a common practice; even greater utilization can be expected with the increasing availability of improved adhesives. Currently, adhesives compete with welding, fusion, and mechanical fastening. However, adhesive bonding offer special advantages. Not least among them is the opportunity of weight savings compared with metal fasteners. It is of special appeal in the automotive industry, where vehicle lightweighting is crucial.

### 117.1 ADVANTAGES

The use of adhesives may indeed be the only sensible route in some instances. The reasons are as follows:

- \* 1. The ability to attach materials that are impractical to bond in other ways. It is obvious that screws or bolts are not suitable for paper, glass or other brittle materials, thin films, fibers, and foams. Moreover, the shape of the substrate may render mechanical fastening difficult or impossible.
2. The ability to join dissimilar materials. Significant differences in thermal coefficient of expansion may disqualify mechanical fastening. Thermal fusion is also disqualified for unlike polymers. Adhesive bonding of dissimilar materials often yields composites with enhanced properties by utilizing the best features or physical properties of each component.
3. Uniform distribution of stress. In a simple bonded overlap, any load applied to the joint is distributed evenly over the entire bonded area as if the material were continuous. In terms of stress vectors in both tensile stress (away from the bond) and shear stress (across the bond), all of the adhesive contributes to opposing the stress. In contrast the holes required for rivets, nails, screws or bolts are stress concentrators or focal points that contribute to failure. Adhesive bonded assemblies generally can resist shock, vibrational and fatigue failure better than mechanically attached assemblies. This often means that adhesive-bonded members can be thinner in cross-section and lighter in weight.

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4. Reduction in joint weight. This feature is partially related to the better performance possible with lighter weight parts because of the elimination of stress concentration points. Reduction in weight is possible because adhesives are generally of low specific gravity, and applied preferentially in thin layers. In many joints the forces of adhesion exceed the cohesive strength of the adherends.
5. Environmental protection. Although usually more important in metal-to-metal joining, the continuous contact between surfaces made by adhesives seals out corrosive or harmful agents. Both gases and liquids can be excluded by the adhesive.
6. Resistance to vibration. Elastomeric adhesives resist the fatigue and subsequent failure that is brought on by repeated deformations. In general the more flexible the adhesive, the greater the resistance to strain occurring in the adherends.
7. Smoother surfaces. Adhesive bonding, like thermal bonding, eliminates such imperfections as rivet-point dimpling, surface spots or projecting portions of devices that are common with mechanical fastening. This reduces finishing costs and makes possible more esthetic and more functional product design.

### 117.2 BASIC REQUISITES

All adhesives must be liquids, or at least capable of some degree of flow. A primary requirement for good adhesion is that the adhesive and adherend surfaces must be in close contact, since the attractive forces that promote adhesion vary as the inverse sixth power of the intermolecular distances. To get substrates close enough to effect a good bond, their surface roughnesses must be made to correspond. In essence, the adhesive must be a fluid because the solid adherend is never smooth in a microscopic sense. For solid polymers, this means that the adhesive must be melted or dissolved in a suitable solvent before application.

The adhesive must also be sufficiently mobile to quickly penetrate holes and depressions in the solid surface. If voids are left when the adhesive solidifies, the joint will be weak.

Finally, the adhesive must solidify to provide sufficient strength to resist unbonding stresses. (Pressure-sensitive adhesives, of course, do not solidify; their function is best described in terms of their viscoelastic properties.) Solidification occurs either through evaporation of a solvent or through chemical reaction (polymerization), frequently called curing. Drying or curing converts the fluid material to a solid, which can be either rigid or elastomeric.



Wetting of the solid surface requires the selection of an adhesive that is suitable in terms of the surface energy or surface tension of the adherend. Any adhesive supplier can furnish this information. However, it is often necessary to alter the surface of the adherend to make it receptive to adhesives.

### 117.3 TYPES



There are five basic physical types of adhesives: curable liquids, solvent cements, hot melts, aqueous, and pressure-sensitive. The curable liquids undergo a chemical reaction or polymerization to attain a nonfluid condition. Often these consist of two parts, each of which is stable by itself but when mixed together undergo a chemical reaction. Solvent cements are simply dilute solutions of fully reacted adhesives that solidify by loss of solvent. Hot melts are 100% solids that become liquids on heating above their melting or softening points; they are applied hot and solidify on cooling.

Aqueous adhesives dissolved or dispersed in water may either simply dry to the proper physical form or undergo a reaction when the water is removed. Solvent-activated adhesives are deposited at the bond line in solid form and rewet with solvent just before making the

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assembly. As with all solvent-borne adhesives, better joints are formed with porous substrates that permit a faster evaporation of solvent.

Pressure-sensitive adhesives do not change form or harden but behave as high-viscosity fluids which, because of an increase modulus as the shear or deformation rate is increased, can be easily removed from the substrate. Pressure-sensitives are frequently used as temporary anchorage for components that must be repositioned.

Another way of looking at adhesives is in terms of their chemical composition. Table 117.1 lists in a simplistic sense the more common physical and chemical types (the actual chemistry of each is more complex and beyond the scope of this chapter). In addition to unlisted additional compositions that fall in each category, there are many mixtures or blends of two or more chemical types, called hybrids. Table 117.2 lists common adhesives and their typical properties.

### 117.4 LIMITATIONS

A key disadvantage of adhesive bonding is the need for fixtures or clamps in many such operations. Another is the slowness, relative to mechanical fastening or fusion welding, of adhesive bonding. Other disadvantages include the following:

**Limited Shelf Life.** Adhesives that depend on a curing reaction and are mixed beforehand, have a relatively short pot or storage mix. Some other adhesives must be carefully stored

TABLE 117.1. Adhesives Classified by Type

Types	Examples
<i>Physical</i>	
Curable liquids (one or two-component)	Epoxies, urethanes, acrylics, silicones
Solvent cements (includes water)	Acrylics, elastomers, vinyls, cellulose, urethanes
Hot melts (100% solids)	Polyamides, EVA, polyesters, urethanes
Aqueous (includes dispersions)	PVA, epoxies, silicones, aminoplastics, rubbers, phenolics
Pressure sensitive	Double-faced tapes
<i>Chemical</i>	
Anaerobic	Methacrylates
Contact	Rubber
Cyanoacrylate	Methyl, ethyl esters
Emulsions	PVA, PVC, rubber, EVA, acrylic, chloroprene
Hot melt	Polyurethane, polyamide, EVA, polyester
Solvent-based (Cements)	Acrylic, chloroprene, nitrile, nitrocellulose phenolic, PU rubber, vinyl
High temperature use	Epoxy, PU, silicone, polyamides
Room temperature cure	Acrylic, cyanoacrylate, epoxy, PU

TABLE 117.2. Common Adhesives

Adhesive	Properties
Acrylic	Room temperature cure
Phenolic	Most require heat
Epoxy	Broad range of properties
Modified polyolefin	Hot melts
Model cement	Resin in solvent
Polyurethane	Broad range
Pressure-sensitive	Mostly in tape form
Emulsions (vinyl, acrylic, rubber)	No solvent
Sealants	Caulking (butyls, silicones)
White glues	PVA dispersion

in order to avoid premature reaction. Additionally, two-part adhesives have a working life that depends on their rate of reaction; the faster the cure, the shorter the pot life. For this reason it may be desirable to use dispensing machines that blend the two components immediately prior to application. In general, if rapid cure under ambient conditions is required, care must be taken not to pre-mix large quantities of the two components.

**Need for Surface Preparation.** Surface contamination of plastics can prevent the necessary intimate contact between adhesive and adherend. For example, low molecular weight substances can bloom to the surface, as can certain additives, creating a "film" that defeats the purpose of the adhesive.

**Solvent Retention.** Where solvents are used, or where a product of the curing reaction is volatile, there is always the danger that failure to dry the adhesive adequately can cause bubbles or voids. These imperfections can seriously weaken the glue line, since they function as stress concentrators that prevent intimate and complete contact of the two surfaces.

**Temperature Limitations.** At elevated temperatures, polymeric adhesives become unstable and will degrade. Some adhesives also become brittle and ineffective at low temperatures. Thus, temperature considerations are important in adhesive selection, and could in fact affect the decision as to whether adhesive bonding is suitable for a particular application.

**Material Limitations.** A primary disadvantage of adhesive bonding (excepting pressure-sensitive) or welding is the inability to disassemble the parts for repair or inspection.

## 117.5 SELECTION FACTORS

Determination of the relative merits of a particular adhesive, involves a number of factors: need for a primer, amount of surface preparation, cure time, fixture time, need for heating, adhesive viscosity, cost, and properties of the cured adhesive.

Some of these considerations relate to the cost of the operation. Elimination of surface preparation and the need for a primer can be important factors in selecting an adhesive. If cure time or consequent fixture time is excessive, the resulting time delays may mitigate against an otherwise useful adhesive. If heating is necessary (either to effect complete cure or to reduce the time for reaction or solvent evaporation) an additional cost is involved. However, most adhesive operations require relatively low capital costs.

Other selection factors relate to the nature of properties of an adhesive. Viscosity must be suitable—either low enough to ensure good wetting of the adherend or high enough to prevent run-off on vertical surfaces. Further, the modulus of the cured or dried adhesive is a factor in terms of the flexibility or resistance to deformation required for the bond line. In turn, these considerations depend on the nature of the plastic and the anticipated use-life stresses or extent of strains.

A most critical factor in selection, of course, is adhesion to the plastic. Not all adhesives will function satisfactorily with all plastic surfaces; even within classes of adhesives or plastics, individual members differ in behavior.

Consideration of environmental resistance depends on the desired use life for the bonded assembly. For instance, water resistance obviously is required if the assembly is intended for outdoor exposure. Phenolics, epoxies, and acrylics are examples of adhesives that weather well. Similarly, the part may have to be exposed to oils or solvents and an adhesive should be chosen with that in mind. Also, certain rubber-based adhesives are contraindicated if long use life is contemplated, since polymers with unsaturated backbones undergo an oxidative degradation with time, which is accelerated by heat or light.

## 117.6 SURFACE PREPARATION

Improved adhesion can be obtained when the surface of a plastic part is prepared correctly. The adhesive must wet, spread and penetrate the rough surface of the adherend.

Cleanliness is a basic requirement in order for the adhesion to make intimate contact with the substrates to be bonded. Surface preparation entails both obtaining a clean surface and, if necessary, altering the surface tension of the substrates to correspond to the surface tension of the adhesive.

Roughening of the plastic surface provides an increased area for bonding and strengthens the joint against shear forces. Accordingly, instructions for surface preparation usually entail both cleaning and abrading the surface. The extent of surface preparation required for a particular bond depends on the physical requirements for the assembled part; more extensive preparation is indicated in instances where extreme in-use stress will be placed on the joint. Thus surface preparation may consist of one or more of the following: solvent cleaning; abrading and solvent cleaning; chemical treatment (to alter surface energetics).

**Solvent Cleaning.** For many operations, particularly where the joint will not be subjected to severe in-use stresses, cleaning the surface may require only a wipe with a suitable solvent or detergent solution. Different solvents are recommended for wiping various plastic surfaces. The choice of solvent is dictated by the solubility properties of the plastic. For example, most common solvents other than alcohols severely attack polystyrene, whereas, nylons are resistant to the same solvents. As a generalization, crystalline polymers are less likely to be attacked by common solvents.

Often, parts are solvent cleaned by more elaborate procedures, such as vapor degreasing, ultrasonic vapor degreasing, or immersion in a series of cleaning agents, which tend to give cleaner surfaces than wiping with cloth or paper. Commonly used solvents are halogenated to minimize flammability concerns. They include methylene chloride, perchloroethylene and similar materials Table 117.3.

**Abrading and Solvent Cleaning.** In the simplest case, plastic components can be wiped with a solvent, abraded with emery cloth and then wiped again to ensure removal of all debris. The plastic surface is not changed chemically but is altered physically; because some of the plastic may be removed the roughened surface now offers the possibility of mechanical interlocking Table 117.3.

TABLE 117.3. Plastic Surface Cleaning<sup>a</sup>

Plastic	Method
Acrylics	Wipe with methanol
Aminoplasts	Scrub (detergent), scour, rinse
Cellulosics	Wipe with alcohol, scour
Epoxy	Degrease (acetone, MEK)
Fluorocarbon	Sodium (solubilized), acetone wash
Nylon	Phenol (12% aqueous); 1:1 resorcinol-ethanol
Polyamide	Solvent-clean (acetone, MEK), scrub
Polyolefin	Oxidize (chromate or radiation)
Polystyrene	Wipe with alcohol
Polyurethane	Wipe with acetone or MEK
Rubbers (NBR, SBR, NBR, Neoprene)	Scrape, scrub with toluene (immerse in acid)
Reinforced plastics	Wipe with MEK

<sup>a</sup>Most surfaces (except those chemically altered) are preferably abraded or roughened.

**Chemical Treatment.** Where optimum adhesion is required, chemical treatment of surfaces may be required. For low energy plastics, such as polyolefins and fluorocarbons, the chemical nature of the plastic surface must almost always be altered in order to give a more polar (higher-energy) surface.

Chemical alterations can be drastic in the case of the low energy plastics. For instance, chromic oxidation involves using a liquid used to remove organic contaminants from glassware. It is hazardous to use, and proper safeguards must be exercised. Similarly the defluorinating solution (utilizing a form of sodium) is dangerous and requires expertise in disposal.

To avoid the problem of hazardous chemicals, sheets of fluorocarbons can be purchased already chemically modified.

An alternative approach to activating plastic surfaces that does not require the use of hazardous fluids is radiation treatment. Such treatment renders polyolefins more amenable to adhesive bonding. Other techniques for enhancing adhesion of plastics include flaming and plasma treatments. Detailed instructions on surface preparation for plastics are available in the literature.

### 117.7 SOLVENT CEMENTING

A variation of adhesive bonding, solvent cementing is particularly useful for noncrystalline thermoplastics. Crystalline polymers generally do not dissolve in ordinary solvents at room temperature.

Solvent cementing depends on active solvents to soften and swell the plastic surfaces; after assembly and evaporation of the solvent, a monolithic clear joint is obtained. Individual solvents are seldom used; a combination of solvents is a more common way to attain the properties desired. Solvents frequently contain some dissolved polymer (of the same type as that to be bonded), to aid in gap filling and to speed up drying. With cements thickened with dissolved polymer, it may be necessary to mask the area around the joint to facilitate removal of excess cement squeezed from the bond line by clamping pressure.

Masking has general application in solvent cementing when the parts to be assembled are soaked in the solvent as a preliminary to adhesion. Cellophane tape rather than masking



paper, is preferred. Parts can also be masked using commercially available masking compounds based on animal glues or gelatins. The masking compounds are applied hot and carefully stripped away for application of the solvent cement.

Another method used in joining is capillary action. Fine wires are used as shims, and the adhesive applied from a dropper or needle. After capillary action has adequately spread the cement, the wires are removed.

Table 117.4 gives some examples of bonding with solvents or solvent cements. The plastics listed are not necessarily always bonded this way, however. For example, ABS can be readily joined using epoxy or acrylic adhesives. This avoids the long drying times associated with solvents. Care must be taken in choosing solvents for polystyrene; caution must be exercised to avoid solvent crazing.

Solvent cementing is the method of choice for many plastics. Acrylics, for example, are readily bonded with such chlorinated solvents such as methylene chloride, ethylene chloride, 1,1,2-trichloroethane, or chloroform. If a more viscous cement is desired, a solution of acrylic chips (from 2 to 8% by weight) in the chlorinated solvent can be used. Cellulosics also are good candidates for solvent bonding. A typical cement for cellulose acetate is a 10% solution of the polymer in a mixture of acetone and methyl cellosolve. For acetate butyrate, a cement based on equal parts of acetone and ethyl acetate is useful.

Poly(vinyl chloride) is frequently bonded using solvents like acetone or methyl ethyl ketone. Sometimes more powerful solvents like cyclohexanone or tetrahydrofuran have to be used. Here the cements not only contain polymer (PVC) but plasticizer as well.

It is important to remember that solvent cementing is generally employed only when the parts to be joined are of the same plastic. Finding a mutually satisfactory solvent mixture for two different plastics is often difficult.

## 117.8 PREFERRED ADHESIVES

Choosing an adhesive for a particular plastic is not so easy as one might suppose. The adhesive providing the strongest bond to a given plastic may not necessarily be the best for a particular job. Primary consideration must be given to the form of the plastic, to its modulus, and to the conditions to which the bonded assembly will be subjected in actual use.

TABLE 117.4. Solvents for Cementing

Plastic <sup>a</sup>	Recommended Solvents <sup>b</sup>
ABS	Blends of acetone, MEK, MIBK, THF or methylene chloride
Acetal	Methylene or ethylene chloride
Cellulose acetate	Acetone or MEK with methyl cellosolve
Poly(methyl methacrylate)	Methylene chloride, chloroform, trichloroethylene
Phenylene oxide	Chlorinated solvents, xylene/MIBK (25/75)
Poly(butylene terephthalate)	Hexafluoroisopropanol
Polycarbonate	Methylene chloride
Polystyrene	Methylene chloride, ethyl, acetate, MEK, trichloroethylene
Polysulfone	Methylene chloride
Poly(vinyl chloride)	Mixed solvents (THF, MEK, MIBK, dioxane) with plasticizer

<sup>a</sup>Usually 1 to 7% of plastic is dissolved in solvent.

<sup>b</sup>MEK = methyl ethyl ketone, THF = tetrahydrofuran, MIBK = methyl isobutyl ketone.

Flexible parts should be bonded with flexible adhesives. When bonding dissimilar materials, the adhesive must be resilient enough to allow for differences in coefficients of thermal expansion.

Choice is complicated by the fact that an unfilled plastic behaves differently from the same material reinforced. It frequently happens that adhesives that give relatively low bond strengths with the unfilled plastic will give greatly improved performance with the same material filled with a polar inorganic substance, particularly after abrading. As earlier noted, organic polymers are low energy materials, in contrast to the higher-energy surface (like glass) to which most adhesive readily adhere.

Table 117.5 lists a number of plastics along with recommended adhesives. However, resin formulations often differ within the same family, and this can affect the performance of the adhesive. For example, structural acrylics are often formulated with different monomers and a particular grade may be more (or less) receptive to one adhesive than to another. However, adhesives can be formulated to vary considerably in polarity and in terms of the flexibility of the cured adhesive. Where flexibility is crucial, rubber-based adhesives may be



TABLE 117.5. Recommended Adhesives for Bonding Plastics

Plastic	Adhesives
ABS	Epoxy, urethane, acrylic, nitrile-phenolic, cyanoacrylate
Acetal	Epoxy, phenolic, polyester, EVA, cyanoacrylate
Cellulose acetate	Urethane, resorcinol-formaldehyde, nitrile-phenolic, rubber-based
Elastomers	Pressure-sensitive based on similar elastomer, urethane
Epoxy	Epoxy (with primers), nitrile-phenolic, acrylic, polyester, resorcinol-formaldehyde
Fluorocarbon	Urethane
Nylon	Phenolic, epoxy, polyamide hot melt
Phenolic	Epoxy, hybrid, phenolic, poly(vinyl acetate), urea-formaldehyde, acrylic, urethane
Phenylene oxide	Polysulfide epoxy, silicone, rubber-based, acrylic cyanoacrylate
Poly(methyl methacrylate)	Cyanoacrylate, nitrile phenolics, epoxy, urethane
Polycarbonate	Epoxy, acrylic, urethane, silicone, cyanoacrylate
Polyolefin (untreated)	Rubber-based, EVA, modified polyethylene
Polyester (linear)	Polyester, cyanoacrylate, nitrile rubber, urethane, acrylic
Polyester (unsaturated)	Acrylic, urethane, neoprene, nitrile-phenolic, epoxy
Polysulfone	Epoxy, vinyl-phenolic, rubber-based, urethane, polyester, cyanoacrylate
Polystyrene	Vinyl acetate-vinyl chloride emulsions, acrylic, polyamide, urethane, epoxy, polyester, hot melt, urea-formaldehyde
Polyurethane	Pressure-sensitive rubber emulsion, polyester, epoxy, phenolic, urethane, nitrile rubber
Poly(vinyl chloride)	
Flexible	Nitrile rubber, neoprene, urethane
Rigid	Epoxy, urethane, acrylic, nitrile rubber, silicone, nitrile-phenolic
Silicone	Silicone
Urea-formaldehyde	Epoxy, nitrile-phenolic, phenolic, polyester, neoprene, cyanoacrylate

preferred over others that have higher adhesion values. Cyanoacrylates, for instance, cure so quickly that jig or fixture time may be avoided, but they are usually quite inflexible.

Plastics and adhesives designed for very high temperature use are not covered in this discussion because there are some special problems with these systems. Manufacturers, particularly those in the aerospace industry, may wish to consult government sources for recommendations.

A comment is in order about a relative newcomer, acrylic structural adhesives. Their great advantage is hardening to handling strength in seconds without heat. This capability translates into markedly reduced process costs and greatly increased process speeds. Structural acrylics are much tougher and higher in impact resistance than cyanoacrylates, and are more resistant to environmental factors.

Offshoots of this adhesive category are UV-curable and visible light-curable types. Otherwise similar to chemically curing grades, they solidify in less than 10 seconds. Their utility for certain applications utilizing transparent plastics is promising.

### 117.9 JOINT DESIGN

There are a variety of ways to effect adhesive joining of plastic components (lap, scarf, strap, etc). Whichever is used, it is always best to design joints to minimize peel stresses. It is important that the joint be designed so that the adhesive is subjected to compressive and shear forces in use.

The effect of joint design can be summarized:

- |                         |                 |
|-------------------------|-----------------|
| • Butt                  | Unsatisfactory  |
| • Lap                   | Practical       |
| • Scarf                 | Very good       |
| • Joggle lap            | Good            |
| • Strap                 | Fair            |
| • Double strap          | Good            |
| • Recessed double strap | Good, expensive |

Other generalizations about adhesive bonding:

1. Width of the bonding area increases joint strength linearly; increasing the length of the bonded area, although beneficial, does not make as great a contribution to strength.
2. Thickness of the bond line should be controlled to about 4 to 6 mils (0.1–0.15 mm) of adhesive. A greater gap in the distance between adherends has a deleterious effect on peel and cleavage strength of the bond.
3. Stiff adherends (high-modulus plastic substrates) are less sensitive to joint geometry than flexible adherends.

### 117.10 APPLYING THE ADHESIVE

Techniques for applying liquid adhesives depend on the sophistication of the job as well as on production-volume needs. Thus, applicator equipment ranges all the way from conveyerized and automated dispensing systems to eyedroppers or brushes. Typical single type applications are

- Spray gun (air or airless)
- Brush

# Metal Surface Characteristics Affecting Organic Coatings

by  
Bruno M. Perfetti



*FEDERATION  
SERIES ON  
COATINGS  
TECHNOLOGY*

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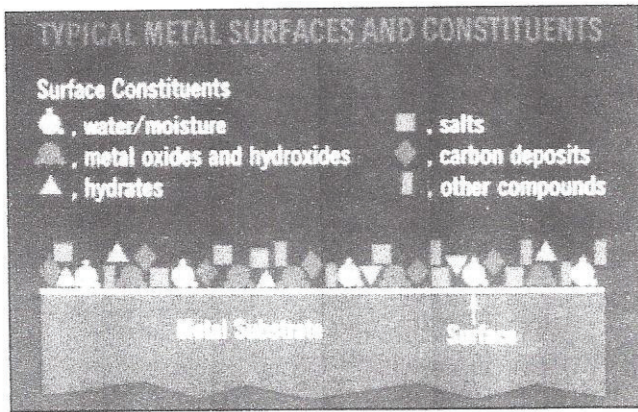


Figure 2—Schematic representation of the typical constituents and contaminants on metal surfaces

the treatments and finishes applied to their surfaces. Although, ideally, the two concerns would or should be complementary, in reality they are often in opposition to one another and the preferred choices and requirements for optimizing the performance of the treatments and coatings in a particular application must be subordinated to the intended function and performance of the metal's end use. The choices one may make in selecting a preparative treatment or practice for a given application are often dictated or limited by circumstances entirely unrelated to the achievement of optimal preparative results. When and where such situations prevail, a well-founded understanding of the technology of surface preparation will be invaluable in effecting a sensible compromise for satisfying the conflicting demands of the problem.

Metal products comprise one of the largest classes of materials which are coated and painted and their usage spans virtually the entire spectrum of consumer goods and markets. Appliances, automobiles, containers, buildings, housing, machinery, ships, trucks, transmission pipe, tanks, fixtures, furniture, and an almost endless list of other items require the application of coatings at some time in their service lives. Each of these applications has unique functional and quality prerequisites and service requirements. Carbon and specially-alloyed steels, coated steels and aluminum, in a variety of grades, are the predominant metals being used in these applications, and each class of metal has its own characteristic response to preparative treatments and coatings. It is interesting that these characteristic responses often do not reflect the properties and compositions of the bulk of the solids concerned but rather are determined by the unique attributes of their surfaces. In turn, the surface attributes of metals are strongly determined by both their chemical composition and metallurgical structure and by the history of their prior processing.

The surface compositions of the various metals consist primarily of a mixture of the oxides, hydrates, and salts of the metallic elements which make up the metal compositions and usually very little of the free metal itself (note Figure 2). This multi-derivatized surface is what must be accommodated by the preparative treatment employed to properly dispose the surfaces to receive the coatings to be subsequently applied. In addition to the naturally derived constituents to be expected on the metal surfaces, as noted, there may also be present contaminants which accumulate on the surfaces of the metals as the result of the prior processing, handling, and various incidental or ambient exposures. These latter constituents on steel might include such species as surface carbon, oils, and rolling and forming lubricants, metal fines, non-metallic surface in-

clusions, rolled-in scales, large surface carbides, dirt and grit, corrosion products, extraneous soils and the by-products of bacterial action, mildews, and other fungal deposits. Zinc surfaces will primarily carry oils, lubricants, corrosion products, metal fines and dusts, dirt and grit, and extraneous soils, but not the other contaminants noted for steel. Aluminum surfaces are very much like those of zinc but they tend to develop very heavy deposits of aluminum oxide. Although the aluminum oxide is not actually a classical contaminant itself, it may inhibit the removal of any true contaminant species otherwise present.

There are no universal means that will remove all the possible contaminants on a metal surface short of actual dissolution or removal of a layer of the surface itself. Alkaline cleaning media normally will be effective against residual oils and lubricants, most soils, dirt and grit, relatively loose metal fines, and bacterial and fungal by-products because these materials are generally sensitive to the dissolution, saponification, emulsifying action, and detergent functions by which alkaline media operate. Except for saponification action, acidic cleaning media are also effective against the soils noted and operate by the three remaining processes noted for the alkaline cleaners. Where organic solvents can be tolerated, solvent cleaning is an excellent means of removing heavy deposits of oils, grease, and other organic materials suitably soluble in various hydrocarbon, ester, ketone, and chlorinated solvents. Vapor degreasing is a common means for solvent cleaning smaller parts easily accommodated in the enclosures required by this practice.

Surface carbon (see Figure 3) generated during the annealing of steel is not readily removed except by electrolytic action or acidic dissolution (pickling) of the metallic surfaces. Surface inclusions and rolled-in scale on steel respond to pickling and surface grinding provided they are only superficial and not deeply embedded. Surface car-

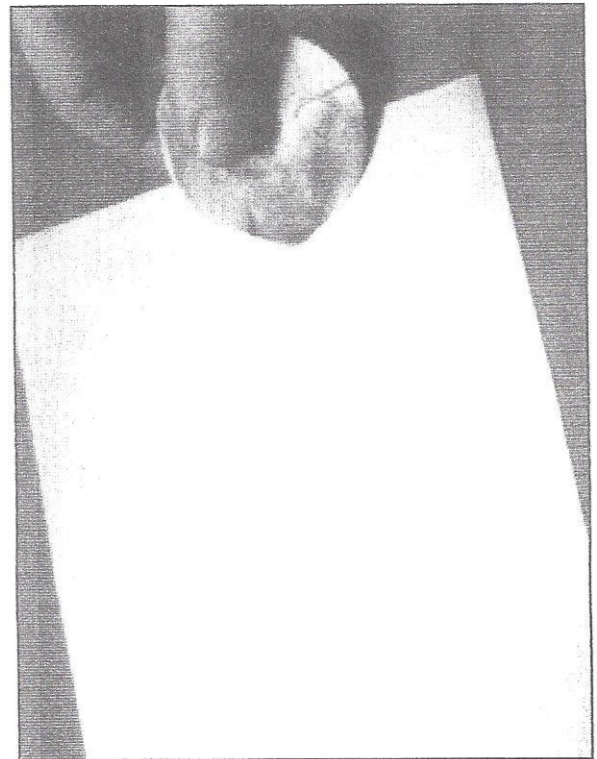


Figure 3—Surface carbon wiped from a steel surface after it was cleaned by a hot alkaline power washing

impair the performance of the pretreatment and the coating applied over it.

### F. Priority of Mechanical Performance Over Surface Requirements

It must be acknowledged that the first priority in the manufacture of a metal substrate is the development of its intended mechanical properties. Metals are used principally because they offer strength, rigidity, and barrier qualities in a particular application (Figure 13). It is only after these mechanical requirements are satisfied that other considerations, such as the surface variables affecting coating, can be addressed. As a rule, the characteristic surfaces which result from the required metallurgical processing of the metal are those that must be handled, whatever their condition, in the preparative processes employed for organic coating. Rarely is a particular metal substrate chosen for an application because it will have the easiest or best surface for subsequent coating. Consequently, compromises are frequently necessary in the selection of a preparative process or in the cost of preparation to accommodate the mechanical property priorities of the substrates being cleaned and treated. An example can be cited to illustrate this point.

A steel structure, such as a bridge, may be constructed with a high strength-low alloy steel to reduce its weight, yet maintain its structural integrity. The subsequent painting of the alloy steel will be somewhat more costly, since the rate of cleaning the surfaces of the alloy steel by abrasive blasting will be slower, because the surfaces tend to be slightly more resistant to oxide removal than those of carbon steel. The higher cost of preparation and painting

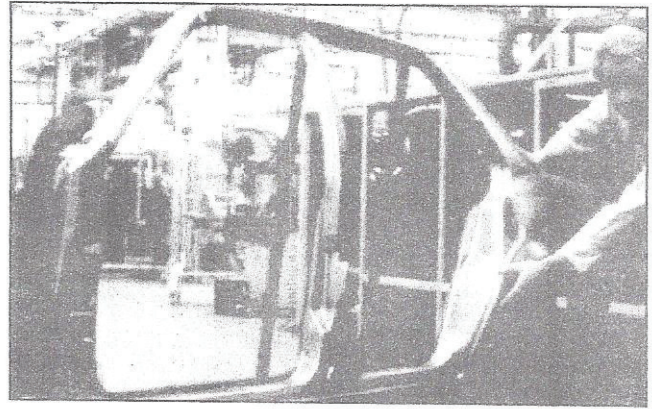


Figure 13—A press drawn quarter panel of an automobile body (The panel illustrates the stringent mechanical requirements which must be satisfied by metal sheet ahead of any finishing demands)

is accepted to gain the advantage of the mechanical strength and rigidity of the alloyed steel structural members.

The foregoing discussions and illustrations are instructive because they clearly point up the necessity of anticipating the numerous chemical, physical, and operating interactions that can impact on the preparative efforts required to enhance the receptivity of metal surfaces for organic coatings. By recognizing the critical elements that contribute to the selection process, one can make the rational and technically sound compromises needed to choose the best preparative methods for a variety of intended purposes.

## II. SOME THEORETICAL AND TECHNOLOGICAL CONSIDERATIONS OF METAL SURFACES

A reasonably good understanding of the scientific principles concerned with metallic elements and their associated compounds is necessary to properly appreciate both the similarities and the differences these materials exhibit when they are prepared for coating. Regarding the technology of metallic substrates, two very important concerns are the characteristic attributes of metals which have an effect on their surfaces and the constitutional features of metallic surfaces which may be altered by the preparative processes preceding coating. Other aspects of metal surfaces which must be considered are the effects of the mechanical and thermal treatments they have undergone and the effects of the surface geometry and texture on their response to coating. Finally, a consideration of the effects of surface energy and wetting phenomena and those of passivation and corrosion resistance properties are needed to complete the theoretical perspectives attending the chemical performance of the metals in cleaning and treatment operations.

### A. Characteristics of Metals Affecting Surfaces

The metals of interest to the current discussion are those which are solids having well defined bounding surfaces. These metal solids will tend to resist deformation

but will also display some elasticity when they are stressed. The surfaces of the solids will ordinarily be polar and possess an inherent high surface energy." Because the metals and solid surfaces of practical interest here are well removed from the high temperatures at which they soften and melt or the very low temperatures where they might fracture and shatter, the impact of the effects of extremes of temperature on their performance is of little concern for the present purposes. Of greater interest are the nature of and disposition of the surface elements, the surface energetics and their consequences, and the effects of prior history of the solid on its chemical responses, because these are the major factors which affect preparative practices and processes.

The elements which reside on a metal substrate may be present in substantially different concentrations and chemical states than those found in the sub-surface or interior composition of the metal. An alloy or a metal with only traces of internal elemental impurities may diffuse one or more of these constituents to the surface of the metal when the metal is processed, such as by heat treatment or hot-rolling, and thus enrich the surface in that element or those elements. Alternately, an element of the bulk composition may migrate to the surface because of a diffusion gradient induced by oxidation of the element at the sur-

# CORROSION ENGINEERING

**MARS G. FONTANA**



## CORROSION ENGINEERING

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two alloys are quite similar in chemical composition. Both alloys exhibit good resistance to stress corrosion.

See Fig. 3-71 for the effect of ferrite on resistance to stress corrosion by CF-3, CF-8, and CF-8M, compared to types 304 and 316.

The Materials Technology Institute published in 1981 two manuals titled *Performance and Reliability of Corrosion Resistant Castings*. Manual No. 5 covers Phase 1, "Causes of Unsatisfactory Performance", and No. 6 covers Phase 2, "Casting Discontinuities."

Table 5-4 lists *mechanical properties* of several stainless steels in each of the four groups. Note the wide range of properties available from these materials. The high-strength materials exhibit good strength-weight ratios for aircraft and missile applications. High hardness is desirable for wear and some applications where resistance to erosion is required (e.g., trim for high-pressure steam valves).

The 200 and 300 series stainless steels all exhibit roughly the same mechanical properties in the annealed condition. The major exception involves cast alloys with duplex microstructures. Note the higher yield strength (and accordingly higher design strength) for CF-8 containing 15% ferrite as compared with type 304. The austenitic steels retain good ductility and impact resistance at very low temperatures and are used for handling liquid oxygen and nitrogen. FCC metals and alloys (austenitic stainless, copper, and aluminum) all possess good properties at cryogenic temperatures. The only method available for hardening the austenitic stainless steels is cold-working. This usually decreases corrosion resistance only slightly, but in certain critical environments a galvanic cell could form between cold-worked and annealed material. Type 301 is utilized mostly in the cold-worked condition for such applications as train and truck bodies. The austenitic steels can be cold-rolled to strengths in the neighborhood of 300,000 lb/in.<sup>2</sup> in wire form. Types 301 and 302 are not used for severe corrosion applications. The former because of its lower Cr and Ni, and the latter because of higher carbon.

High-temperature properties are discussed in Chap. 11.

### 5-9 Aluminum and Its Alloys

Aluminum is a reactive metal, but it develops an aluminum oxide coating or film that protects it from corrosion in many environments. This film is quite stable in neutral and many acid solutions but is attacked by alkalis. This oxide film forms in many environments, but it can be artificially produced by passage of electric current. This process is called anodizing. The high-copper alloys are utilized mainly for structural purposes. The copper-free or low-copper alloys are used in the process industries or where better corrosion resistance is required.

### 5-10 Magnesium and Its Alloys

Magnesium is one of the lightest commercial metals, specific gravity 1.74. It is utilized in trucks, automobile engines, ladders, portable saws, luggage, aircraft, and missiles because of its light weight and also good strength when alloyed. However, it is one of the least corrosion resistant and is accordingly used as sacrificial anodes for cathodic protection (Chap. 3) and dry-cell batteries. It is generally anodic to most other metals and alloys and must be insulated from them.

Magnesium exhibits good resistance to ordinary inland atmospheres due to the formation of a protective oxide film. This protection tends to break down (pits) in air contaminated with salt, and protective measures are required. These include coatings and "chrome" pickling, which also provides a good base for the coating. Corrosion resistance generally decreases with impurities and alloying. Alloys are quite susceptible to stress corrosion and must be protected. Presence of dissolved oxygen in water has no significant effect on corrosion. The metal is susceptible to erosion corrosion. Magnesium is much more resistant than aluminum to alkalis. It is attacked by most acids except chromic and hydrofluoric. The corrosion product in HF acts as a protective film.

Magnesium and its alloys are available in a variety of wrought forms and die castings. Tensile strengths in the approximate range 15,000 to 50,000 lb/in.<sup>2</sup> are obtainable.

### 5-11 Lead and Its Alloys

Lead is one of our oldest metals. It was used for water piping during the time of the Roman Empire, and some of it is still in operation. Lead ornaments and coins were utilized several thousand years ago. Lead forms protective films consisting of corrosion products such as sulfates, oxides, and phosphates. Most of the lead produced goes into corrosion applications: a large portion involves sulfuric acid. (See isocorrosion chart in Chap. 7.) Lead and its alloys are used as piping, sheet linings, solders (Pb-Sn), type metals, storage batteries, radiation shields, cable sheath, terneplate (steel coated with Pb-Sn alloy), bearings, roofing, and ammunition. Lead is soft, easily formed, and has a low melting point. Lead-lined steel is often made by "burning on" the lead. It is subject to erosion corrosion because of its softness.

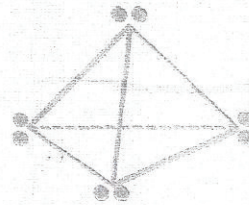
When corrosion resistance is required for process equipment, chemical lead containing about 0.06% copper is specified, particularly for sulfuric acid. This lead is resistant to sulfuric, chromic, hydrofluoric, and phosphoric acids: neutral solutions: seawater: and soils. It is rapidly attacked by acetic acid and generally not used in nitric, hydrochloric, and organic acids.

Chemical lead exhibits a tensile strength of about 2300 lb/in.<sup>2</sup> at room



# GENERAL CHEMISTRY

*John Arrend Timm*



**GENERAL CHEMISTRY**

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## CHAPTER THIRTY-FOUR

### CARBON

Less than 0.2 per cent of the earth's crust is carbon. Yet we can safely say that had carbon been omitted from the roster of elements we should not exist. All organic compounds are compounds of carbon.

**1. Occurrence** Carbon occurs as the pure element in nature in two allotropic forms, diamond and graphite. The Belgian Congo is the world's richest source, although deposits in Brazil and South Africa are important. Owing to the large demands of the war for diamonds in grinding tools and for dies through which wire is drawn, the deposits in Arkansas are being developed. Deposits of graphite, a second allotropic form of carbon, occur in Ceylon, Russia, Germany, Mexico, Madagascar, and Canada. Although anthracite coal is 94 per cent carbon, its carbon atoms are combined with one another and with hydrogen atoms. Hence, strictly speaking, coal contains little free carbon.

Inorganic compounds of carbon include carbon dioxide in the atmosphere, and carbonates. Limestone, chalk, and marble are calcium carbonate. Magnesite,  $MgCO_3$ , is abundant, and whole mountain ranges are composed of dolomite,  $MgCO_3 \cdot CaCO_3$ . We have mentioned that all organic substances are carbon compounds.

**2. Properties.** No one has to describe the beauty of a diamond, but its extreme hardness, which is really its most valuable property, may be overlooked. It is more than twice as hard as its nearest competitor. Hardness is the ability of a substance to resist penetration of its surface by another substance. The relative hardness of two substances can be determined easily by rubbing an edge of one on the surface of the other, and

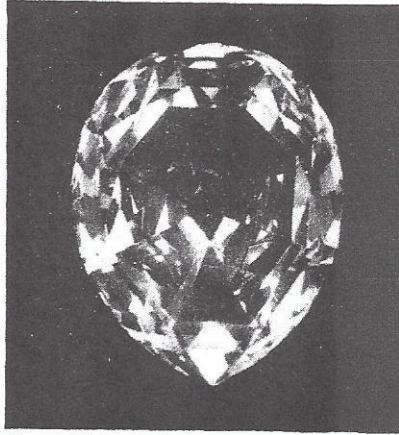


FIG. 34-1. Star of Africa diamond.  
(Courtesy of American Museum of Natural History, New York.)

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**Allopatric** (*al'ə-pā'tr'ik*) *adj.* **allo-** + **patric** (*al'ə-pā'tr'ik*) *adj.* **Ecol.** Occurring in separate, widely differing geographic areas. [**ALLO-** + **Gk. patria**, fatherland (< *pater*, father) + **-ic**.] — **allo-patric-ally** *adv.*

**al-lo-pha-ne** (*al'ə-fān'*) *n.* An amorphous, translucent, variously colored mineral, essentially hydrous aluminum silicate. [**Gk. allophanēs**, appearing otherwise: *allos*, other + *phainein*, to appear.]

**al-lo-phon-e** (*al'ə-fōn'*) *n.* Any of the variant forms of a phoneme. For example, the aspirated *p* of *pit* and the unaspirated *p* of *spit* are allophones of the English phoneme *p*. — **al-lo-phon'ic** (*-fōn'ik*) *adj.*

**al-lo-pu-ri-nol** (*al'ə-pyōōr'ə-nōl'*) *n.* A drug, C<sub>5</sub>H<sub>7</sub>N<sub>3</sub>O<sub>3</sub> used to treat gout by promoting uric acid excretion. [**ALLO-** + **PURIN(E)** + **-OL**.]

**al-lor-none** (*al'ər-nūn'*) *adj.* Characterized by either complete response or total lack of response or effect, as in neurological action above a threshold.

**al-lo-ster-ic** (*al'ə-stēr'ik*) *adj.* Of or relating to molecular binding to an enzyme at a site other than the enzymatically active one.

**al-lot** (*ə-lōt'*) *tr. v.* **-lotted, -lot-ting, -lots.** 1. To distribute by lot; apportion. 2. To give or assign as one's portion; allocate; *al-lot three weeks to a project.* [**ME** *alotten* < **OFr.** *aloter*: *a-*, to (< **Lat. ad-**) + *lot*, portion, of Germanic orig.] — **al-lot'ter** *n.*

**al-lot-ment** (*ə-lōt'mənt*) *n.* 1. The act of allotting. 2. Something that is allotted. 3. A portion of a serviceman's pay set aside for a member of his family or for insurance.

**al-lo-tro-pe** (*al'ə-trōp'*) *n.* A structurally differentiated form of an allotropic element. [**Back-formation** < **ALLOTROPY**.]

**al-lot-tro-py** (*ə-lōt'rə-pē*) *n.* The existence, esp. in the solid state, of two or more crystalline or molecular structural forms of an element. — **al-lo-trop'ic** (*al'ə-trōp'ik*), **al-lo-trop'i-cal** *adj.* — **al-lo-trop'i-cally** *adv.*

**al-lot-ta-va** (*al'ə-tāv-ə, al'ō-*) *adv.* **Mus.** At an octave higher or lower than written. Used as a direction. [**Ital.**, at the octave.]

**al-lot-tee** (*ə-lōt'ē*) *n.* One to whom something is allotted.

**all out** *adv.* With every possible effort.

**all-out** (*al'out'*) *adj.* Using all one's resources: *an all-out effort.*

**all over** *adv.* 1. Over the whole area or extent: *embroidered all over with roses.* 2. Everywhere: *searched all over for the money.* 3. In all respects: *She's her grandmother all over.*

**all-over** (*al'ə-vər*) *adj.* Covering an entire surface.

**al-low** (*ə-lou'*) *tr. v.* **-lowed, -low-ing, -lows.** 1. To let do or happen; permit. 2. To acknowledge or admit; concede: *al-low the legality of a claim.* 3. To permit to have: *allow oneself five dollars a day.* 4. To make provision for: *allow time for a coffee break.* 5. To permit the presence of: *No pets allowed.* 6. To provide (the needed amount): *allow funds in case of emergency.* 7. To admit; grant: *I allow that to be true.* 8. To allow as a discount or in exchange: *allowed me twenty dollars on my old typewriter.* — **phrasal verb.** **allow of.** To permit: *a treatise allowing of several interpretations.* [**ME** *allowen*, to approve, permit < **OFr.** *alouer* < both **Lat. allaudare**, to praise, and **Med. Lat. allocare**, to allocate.] — **al-low'a-ble** *adj.* — **al-low'a-blely** *adv.*

**al-low-ance** (*ə-lou'əns*) *n.* 1. The act of allowing. 2. Something that is allowed. 3. Something given, as money, at regular intervals or for a specific purpose: *a travel allowance.* 4. A price reduction granted in exchange for used merchandise: discount. 5. A consideration for possibilities or modifying circumstances: *an allowance for breakage.* 6. An allowed difference in dimension of closely mating machine parts. — *tr. v.* **-anced, -anc-ing, -ances.** 1. To restrict to an allowance. 2. To put on an allowance.

**al-low-ed-ly** (*ə-lou'ed-lē*) *adv.* By general admission; admittedly.

**al-loy** (*al'oi', ə-loi'*) *n.* 1. A homogeneous mixture or solid solution, usually of two or more metals, the atoms of one replacing or occupying interstitial positions between the atoms of the other. 2. The relative degree of mixture with a base metal; fineness. 3. Something added that lowers value or purity. — *tr. v.* (*ə-loi', al'oi'*) **-loyed, -loy-ing, -loys.** 1. To combine (metals) to form an alloy. 2. To lower purity or value of (a metal) by mixing with a cheaper metal. 3. To debase by the addition of an inferior element. [**OFr.** *aloi* < *aloter*, to alloy < **Lat. alligare**, to bind to: *ad-*, to + *ligare*, to bind.]

**al-lur-ing** (*al'lūr'ing*) *adj.* Useful in many ways.

**all right** *adv.* 1. Satisfactory; average. 2. Correct: *These figures are perfectly all right.* 3. Uninjured. 4. Very well; yes. 5. Without a doubt: *He's a fool, all right.*

**Usage:** It is still not acceptable to write *all right* as a single word, *alright*, despite the parallel to words like *al-ready* and *al-together* and despite the fact that in casual speech the expression is often pronounced as if it were one word.

**all-right** (*al'rit'*) *adj.* **Slang.** 1. Dependable; honorable: *an all-right fellow.* 2. Good; excellent: *an all-right movie.*

**all-round** (*al'raund'*) *adj.* Variant of **all-around**.

**All Saints' Day** *n.* November 1, a church festival in honor of all saints.



allspice

berry



almond

**all-seed** (*al'sēd'*) *n.* Any of several plants having many seeds, such as knotgrass.

**All Souls' Day** *n.* November 2, observed by the Roman Catholic Church as a day of prayer for souls in purgatory.

**all-spice** (*al'spīs'*) *n.* 1. A tropical American tree, *Pimenta officinalis*, having small white flowers and aromatic berries. 2. The dried berries of the allspice, used whole or ground as a spice.

**all-star** (*al'stār'*) *adj.* Made up wholly of star performers: *an all-star cast.* — *n.* **Sports.** A player chosen for an all-star team.

**all-time** (*al'tīm'*) *adj.* **Informal.** Of all time: *an all-time attendance record.*

**all told** *adv.* With everything considered: *in all.*

**al-lude** (*ə-lōōd'*) *intr. v.* **-lud-ed, -lud-ing, -ludes.** To make an indirect reference to. [**Lat. alludere**, to play with: *ad-*, to + *ludere*, to play < *ludus*, game.]

**Usage:** *Allude* and *allusion* are often used where the more general terms *refer* and *reference* would be preferable. *Allude* and *allusion* apply to indirect reference that does not identify specifically. *Refer* and *reference*, unless qualified usually imply direct, specific mention.

**al-lure** (*ə-lōōr'*) *v.* **-lured, -lur-ing, -lures.** — *tr.* To entice with something desirable; tempt. — *intr.* To tempt or fascinate. — *n.* The power to entice or tempt; fascination. [**ME** *alurer* < **OFr.** *alurer*: *a-*, to (< **Lat. ad-**) + *loire*, bait, of Germanic orig.] — **al-lure-ment** *n.* — **al-lur'er** *n.* — **al-lur-ing-ly** *adv.*

**al-lu-sion** (*ə-lōō'zhan*) *n.* 1. The act of alluding; indirect mention. 2. An indirect, but pointed or meaningful reference. — **See Usage note at allude.** [**LLat.** *allusio*, a playing with < **Lat. alludere**, to play with. — **see ALLUDE.**]

**al-lu-sive** (*ə-lōō'siv*) *adj.* Containing or making allusions suggestive. — **al-lu-sive-ly** *adv.* — **al-lu-sive-ness** *n.*

**al-lu-vi-a** (*ə-lōō'vē-ə*) *n.* A plural of alluvium.

**al-lu-vi-al** (*ə-lōō'vē-əl*) *adj.* Of, pertaining to, or composed of alluvium.

**alluvial fan** *n.* A fan-shaped accumulation of alluvium deposited at the mouth of a ravine.

**al-lu-vi-on** (*ə-lōō'vē-ən*) *n.* 1. Alluvium. 2. The flow of water against a shore or bank. 3. Inundation by water; flood. 4. **Law.** The increasing of land, esp. along a river bed, by deposited alluvium. [**Lat. alluvio** < *alluere*, to wash against: *ad-*, to + *luere*, to wash.]

**al-lu-vi-um** (*ə-lōō'vē-əm*) *n.*, *pl. -vi-ums or -via* (*-vē-ə*). Sediment deposited by flowing water, as in a river bed, flood plain, or delta. [**Lat. alluvius**, alluvial < *alluere*, to wash against. — **see ALLUVION.**]

**ally** (*ə-lī, al'ī*) *v.* **-lied, -ly-ing, -lies.** — *tr.* 1. To unite or connect in a formal relationship or bond, such as by treaty. 2. To unite or connect in a personal relationship, such as friendship or marriage. — *intr.* To enter into an alliance. — *n.* (*al'ī, ə-lī*), *pl. -lies.* 1. One that is united with another in some formal or personal relationship. 2. A friend or close associate. [**ME** *allien* < **OFr.** *alier* < **Lat. alligare**, to bind to — **see ALLOY.**]

**al-yl** (*al'əl*) *n.* The univalent organic radical CH<sub>2</sub>:CHCH<sub>2</sub>. [**Lat. allium**, garlic + **-yl** (so called because it was first obtained from garlic).] — **al-yl'ic** (*ə-lil'ik*) *adj.*

**Al-ma-gest** (*al'mā-jest'*) *n.* 1. An exhaustive chronicle on astronomy and geography compiled by Ptolemy about A.D. 150. 2. **almagest.** Any of several medieval treatises concerned with astronomy or alchemy. [**ME** *almageste* < **OFr.** *Ar. al-majisti*: *al*, the + **Gk. megistē** (*suntaxis*), greatest (composition), fem. of *megistos*, greatest, superl. of *mega-*, great.]

**al-ma-ma-ter** or **Al-ma-Ma-ter** (*al'mə mā'tər, al'mə*) *n.* 1. The school, college, or university that one has attended. 2. The anthem or school song of an institution of higher learning. [**Lat.**, nourishing mother.]

**al-ma-nac** (*al'mā-nāk, al'-*) *n.* 1. An annual publication including calendars with weather forecasts, astronomical information, tide tables, and other related tabular information. 2. An annual publication composed of various lists, charts, and tables of useful information in many unrelated fields. [**ME** *almenac* < **Med. Lat. almanach**, perh. **Gk. almenikhiaka**, calendars.]

**al-man-dine** (*al'mān-dēn'*) also **al-man-dite** (*-dīt'*) *n.* A deep violet-red garnet, essentially FeAl<sub>2</sub>Si<sub>2</sub>O<sub>7</sub>, found in metamorphic rocks and used as a gemstone. [**ME** *alabandine* < **Lat. alabandinus** < *Alabanda*, a town in ancient Asia Minor famous for its jewelry.]

**al-might-y** (*al-mī'tē*) *adj.* 1. Having absolute power; all-powerful. 2. **Informal.** Great or extreme: *an almighty ail-* — *adv.* **Slang.** Extremely: *almighty scared.* — *n.* **The Almighty.** God. [**ME** *almightig* < **OE** *almehtig*; *eall*, all + *miht*: *miht* < *miht*, might.] — **al-might'i-ly** *adv.*

**al-mond** (*al'mānd, am'ənd*) *n.* 1. A small tree, *Prunus amygdalus*, native to the Mediterranean region, having pink flowers and fruit containing an edible nut. 2. The nut of the almond tree, ellipsoid in shape, and having a soft, yellowish-tan shell. 3. Something having the oval, pointed form of an almond. 4. A pale tan. [**ME** *almande* < **OFr.** < **LLat.** *amigdala*, alteration of **Lat. amygdala** < **Gk. amygdalē**.]

**al-mo-ner** (*al'mə-nər, ə'mə-*) *n.* 1. One who distributes alms. 2. **Chiefly Brit.** A social worker in a hospital. [**ME** *aumer* < **OFr.** *aumonier*, ult. < **Lat. elemosynā**, alms.]

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THIRD EDITION**

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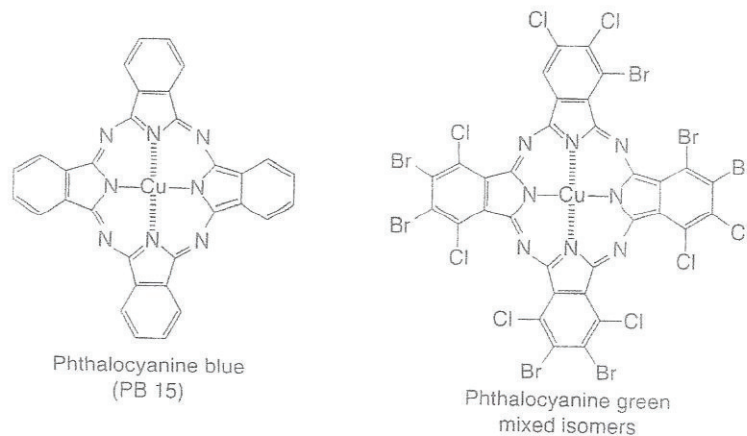


Figure 20.4. Representative phthalocyanine pigments.

The alpha form is redder, but not as stable; in some cases, when some grades of the alpha form are used, there can be serious problems of change of color and strength during storage of coatings or during baking. More stable alpha form pigments are available; these incorporate various additives that stabilize the crystal form and minimize problems with flocculation of dispersions. Some grades of phthalocyanine blue are slightly chlorinated; these have greener blue shades.

Phthalo greens are made by halogenating copper phthalocyanine to produce mixtures of isomers in which many of the 16 hydrogens of CPC have been replaced with chlorine or mixtures of chlorine and bromine. Phthalo greens with 13 to 15 chlorines but no bromine have blue-green shades. Partial replacement of chlorine with bromine shifts the color toward a yellow-green shade. The yellowest shades have a high ratio of bromine to chlorine, an example is PG 36, which has on average about 9 bromines and 3 chlorines.

#### 20.2.4. Black Pigments

Almost all black pigments used in coatings are carbon blacks. They absorb UV radiation as well as light, and with most binders, black colors are the most stable on exterior exposure. Carbon blacks are made by a variety of processes of partial combustion and/or cracking of petroleum products or natural gas. Depending on the process, the particle size and therefore the degree of *jetness* (intensity of blackness) varies. High color *channel blacks* have the smallest particle sizes, with diameters of 5 to 15 nm, and have the highest jetness. They are used when intensely black, glossy coatings are desired. *Furnace blacks* have larger particle sizes, are lower in cost, and give less jet black coatings. Various grades are available, with average diameters of 50 to 200 nm. *Lampblacks* have a still larger particle size, on the order of 0.5  $\mu\text{m}$ , and have lower color strengths than other carbon blacks. They are primarily used in making gray coatings. They are preferable to high-color blacks for this purpose: if a small excess of high color black is added by mistake, it may be necessary to increase the batch size 50% or more to make up for the mistake. The shade of gray obtained changes much more slowly with the addition of lampblack, making color matching easier.

# **ORGANIC COATINGS**

**SCIENCE AND TECHNOLOGY  
THIRD EDITION**

**ZENO W. WICKS, JR. • FRANK N. JONES  
S. PETER PAPPAS • DOUGLAS A. WICKS**

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