



Coating Types and Characteristics

An Online Continuing Education Course for Engineers

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Introduction

All coatings—whether used for corrosion protection, to provide good aesthetics or a pleasing appearance, or for any other purpose—will contain a film-forming material. This material may be organic or inorganic and, after application, may form a hard, impervious film, a soft porous film, or combinations in between. Furthermore, the film-forming material may be clear (unpigmented) or filled with a variety of different pigments, depending on its function. When the film-forming material (resin) contains pigments, it is called a binder. The binder will hold the pigment particles together and to the substrate over which it has been applied. When the binder (resin plus pigment) is dissolved in a solvent to make it liquid, the combination (solvent, binder, and pigment) is considered to be a vehicle. The term vehicle comes from the ability to transport and apply the liquid to the surface being coated. Once on the surface, the solvent evaporates and the vehicle becomes a pigment-binder system. Application properties of the paint usually are characterized by the vehicle in a liquid condition. The viscosity, rate of solvent evaporation, and consistency of the wet coating are most important during application. After application, the pigments determine the corrosion-inhibitive properties and, generally, the color and some flow control properties of the applied coating. The binder determines the weatherability of the coating, its environmental resistance, and the coating's ability to function in a given environment. The required surface preparation, and often the application equipment and techniques, are determined by the binder.

The principal mechanisms by which binders form films are reaction with oxygen from the air (oxidation), evaporation of the solvent from the vehicle (solvent evaporation), or chemical crosslinking (polymerization). The coating film attained by these mechanisms can be either thermoplastic or thermosetting. Thermoplastic materials deform and soften on exposure to heat. Thermoset materials do not deform and remain hard upon heat exposure. Each type of coating resin or binder categorized by its film-forming mechanism, different types of pigments, and the various solvent families will be discussed. Drying oils are an integral part of some coating formulations, and they as well as driers that aid in the drying reaction will be covered. Miscellaneous additives that are formulated into many coatings for specific purposes are itemized and discussed. Sections are presented on powder coatings, thermal spray organic and inorganic coatings, and galvanizing tapes and wraps. Problems with VOCs also will be discussed.

Film-Forming Mechanisms

Coating binders can be subcategorized according to the mechanism described above. However, with both oxidation and most polymerization film-forming mechanisms, solvent evaporation occurs initially, followed by a subsequent chemical reaction consisting of either a reaction with oxygen or chemical crosslinking. Solvent evaporative coatings also are called thermoplastics because, when heated, they become plastic and can soften and deform.

Oxidation and chemically crosslinked coatings “set” and harden when cured; they do not soften or deform on heating and, therefore, are called thermosets. After application, most coatings “dry” by solvent evaporation to form a film that feels dry to the touch. However, the dried coating may not be cured, and additional chemical reactions may be required. Oxidation coatings require crosslinking with oxygen from the air, and polymerization coatings require a crosslinking chemical reaction between two or more co reactants to attain their final physical and chemical properties.

a. Oxidation (thermoset). Thermoset coating types dry and ultimately crosslink by reaction with oxygen from the atmosphere. All such coatings in this class contain drying oils that consist mainly of polyunsaturated fatty acids. The drying oil frequently is combined with a resin, usually by cooking or heating to enhance water and chemical resistance. The curing reaction is accelerated by the presence of metallic salts as driers. After application, the coating dries by solvent evaporation. However, to attain maximum chemical and moisture-resistance properties, the oil must react with oxygen from the air to crosslink, cure, and further harden. The auto-oxidation reaction occurs at a relatively fast rate shortly after application of the wet paint; and it continues throughout the life of the coating, although at a much slower rate. For most oil-based coatings, suitable moisture and chemical resistance occur within a few days after application, although maximum resistances may not be obtained until months or years after application. In time (often 20 or 30 years later), the oxidation reaction and continued drying of the oleoresinous binder system leads to cracking, embrittlement, and deterioration of the coating film.

b. Solvent evaporation (thermoplastic). A second film-forming mechanism is solvent evaporation. The solvent within which the resin is dissolved or emulsified may be water or an organic solvent. The liquid resin returns to a solid material when the solvent evaporates. The coating is formed as a result of solvent evaporation and drying, with no attendant crosslinking or polymerization. Solvent-based coating systems that dry solely by solvent evaporation (vinyls and chlorinated rubbers) have their usage severely restricted because of VOC regulations. These resins must be dissolved in relatively high amounts of noncompliant solvents to be formulated into a corrosion-resistance protective coating. Latex emulsion coatings consist of pigmented synthetic resin particles emulsified in water. Because latex emulsion coatings dry by water evaporation (and perhaps one percent or less of a coalescing organic solvent), coatings formulated in this fashion comply with VOC legislation; and they have rapidly advanced in recent years to become environmentally safe, long-lasting, protective coating systems. Thermoplastic coatings in the context used here are coatings that dry principally, or solely, by water or solvent evaporation; they do not undergo chemical crosslinking. Principal coatings in this class are acrylic lattices, solvent cutbacks, and hot melt bituminous coatings and vinyl coatings (zinc chromate vinyl butyral wash primers, vinyl chloride-vinyl acetate copolymers, and waterborne vinyls).

c. Chemically crosslinked (thermoset). Thermoset coatings, by definition, are coatings that are “set,” and are nondeformable when exposed to elevated temperatures. Thermoset coatings achieve their characteristic “set” and the ability to resist heat deformation by virtue of a three-dimensional crosslinking. This crosslinking is achieved by coreacting two or

more monomers, with at least one monomer having a functionality of three or greater, and the other a functionality of at least two. (The functionality is the number of reaction sites where crosslinking can occur.) This film-forming mechanism involves a chemical reaction combining smaller molecules (mers) to create a larger molecule (polymers). The reactions can consist of the same kind of mer units reacting to form larger molecules (homopolymers) or different mer units reacting to form copolymers, tripolymers, or, generically, polymers. After crosslinking, and depending on the type and extent of crosslinking, the resin system is solvent resistant, ranges from tough and flexible to hard and brittle, and does not significantly deform on the application of heat. In coating formulations, most coreactive coating systems are supplied in multipack systems consisting of two or more containers that must be mixed prior to application. However, some thermoset materials react with moisture from the air (moisture and ketimine curing isocyanates) and can be supplied as a one-package system. After application in all instances, the coating system, when properly applied and cured, forms a single, extremely large molecule by virtue of its polyfunctional crosslinking. When suitably dissolved in a solvent and pigmented, many coreactive materials can be formulated into a protective coating. Some of the more commonly used protective coating systems are based on catalyzed epoxy resins, polyurethane reactions, acrylic/vinyl ester resins, and modifications thereof. Each of these coating systems will be discussed later. Polymerization reactions are becoming increasingly important in the formulation of modern VOC-compliant coating systems. Small molecule units, that by virtue of their low molecular weight are liquid, can be reacted with other low molecular weight liquid molecules to form a higher molecular weight molecule that will harden to form a solid (nonliquid) protective film. The most successful adaptations to manufacturing low VOC coatings have been two-pack, chemically cured coating systems such as the epoxy, polyurethane, polyester, and vinyl ester systems.

Binders (Resins)

The binder, sometimes called a resin, and a suitable solvent (to make it liquid) are combined to form the vehicle. Pigment particles then are dispersed and mixed into the liquid resin, and the paint is packaged, usually in a can or pail, for sale. Upon use, the liquid paint is applied—perhaps by brush, roller, or spray—after which the solvent volatilizes, the liquid resin dries or cures, and the pigment particles “bind” together and to the surface being painted. Binders may be natural or synthetic resins and may be organic or inorganic. The binder used in a particular coating system is primarily responsible for the coating's chemical, water, and UV light-resistant properties. However, to optimize protective capabilities, most coatings must be pigmented to provide color and opacity, to reduce shrinkage, and to obtain enhanced moisture and chemical resistance. When properly applied and dried and/or cured, the pigmented binder provides the decorative, protective layer referred to as a paint or coating. The characteristic of the binder and its method of drying and/or curing determine the mechanism of film formation. Many of the natural resins used as binders are derived from exudations from trees or insect secretions. Synthetic binders are generally by-products of chemical refining or manufacturing processes. These resins are man-made and, when refined and modified for coatings use, can be used as film formers for protective and decorative coatings. Because of their improved moisture,

chemical, and UV resistant properties compared with the natural resins, synthetic resins have obtained widespread use in a variety of different service environments as corrosion-protective coatings.

a. Natural resins (oxidative). Natural resins are derived from tree exudations, fossilized vegetable remains, or insect secretions. Natural resins derived from tree exudation may be named after the region from which they originated; this accounts for some exotic names such as Kauri, Batu, Sandric, and others. Natural resins generally are cooked with drying oils to make varnishes with faster drying rates, higher gloss, and harder films than can be attained from the oil alone. Some were used as a sole binder in so-called spirit varnishes, i.e., the resin was simply dissolved in volatile solvents. When applied to a surface, the solvent evaporated from the spirit varnish leaving a film of the resin on the substrate. This type of drying mechanism involves no substantial chemical change and is typical of what today is called lacquer. In general, clear films of natural resin, oil varnishes, and spar varnishes have poor exterior durability. Accordingly, these resins are no longer used extensively except for interior use such as for wood furniture finishing.

- (1) Rosins. The natural resin, rosin, is obtained from oleoresin, a sap exudation of pine trees. Lighter fractions (i.e., the fastest evaporating, when heated, also usually the lowest molecular weight) of the sap include turpentine, dipentene, and pine oil. Rosins generally have a high acid value and poor resistance to water and alkalis. They also are sensitive to oxygen in the air and are tacky to the touch. Rosins are most commonly used to produce rosin maleic esters, and they are adducted (partially reacted) with maleic anhydride and then esterified with glycerol. These esters sometimes are combined with castor and/or soya oils to reduce yellowing and to increase the hardness and gloss of paints. Coatings manufactured from rosin maleic ester binders are clear and unpigmented and are intended for interior wood surfaces and furniture finishes.
- (2) Shellac. Lac is a resinous secretion of a coccid insect from India and Thailand used to make shellac. The dry secretion is collected, crushed, and washed. Afterward, it is melted and dried in sheets that are broken up and exported for use as an alcohol-soluble coating resin. The shellac film is both hard and fairly elastic, and it has a variety of uses including knot sealers and sealers for wood and plaster.
- (3) Copals. Natural resins called copals are derived from fossilized or semifossilized vegetable remains. These resins have high carboxyl-functional hydrocarbons of high acid number and, therefore, are reactive. The fossil resins frequently are cooked with vegetable oils to result in a resin with an improved drying time, hardness, gloss, and water or alkali resistance. Because of their flexibility, these resins most commonly are used for coating paper (paper labels).

b. Oil-based alkyds (oxidative).

- (1) Alkyd resins are derived as a reaction product of polyhydric alcohols and polybasic acids. Alkyds use a polybasic acid derived from a semidrying or drying oil so the

resin formed can undergo auto-oxidation at any temperature. This definition also includes polyester resins, of which alkyds are a specific type. The properties of alkyd coatings predominantly are the result of the properties of the drying oil used in the manufacture of the alkyd resin. Drying time, hardness, color, and moisture sensitivity all depend on the drying oil, its type, and the degree of unsaturation (available crosslinking sites). Soybean oil has been shown to give good drying rates and good color retention. However, linseed oils generally dry faster but darken on exposure to light. Castor and coconut oils have good color-retentive properties and are used as plasticizing resins because of their nonoxidizing characteristics.

(2) The amount of oil combined with the resin influences the protective capability of the applied alkyd coating. Long oil modification (94.6 liters [25 gallons] of oil per 45.36 kilograms [100 pounds] of resin) has moisture and chemical resistance and is used for applications where the coating must have a greater ability to resist water and chemicals. Short oil modification (less than 37.85 liters [10 gallons] of oil per 45.36 kilograms [100 pounds] of resin) are fast-drying coatings that cure at a temperature of approximately 95 °C (200 °F) for a few minutes. Medium oil modification (approximately 94.6 liters [10 to 25 gallons] of oil per 45.36 kilograms [100 pounds] of resin) is a practical compromise between the long and short oil modifications. They harden within 24 hours and are the oil of choice for most industrial alkyd coating systems.

(3) All alkyd coatings cure and cure by auto-oxidative crosslinking. The rate of the drying oil, and the type of the drying oil, cannot be used in immersion or near immersion conditions. They are highly chemical resistant to immersion or near immersion conditions. They are low cost, ease of application, and adhere to relatively poorly prepared, rough surfaces. These characteristics make them the coating system of choice on steel exposed to nonchemical atmospheric service. Alkyd coatings are widely used for structural steel such as the exterior of buildings, handrails, cranes, gantries, etc. Alkyd coating systems should not be used in immersion or in environments in which the coating will be subjected to prolonged wetting, dampness, or condensing humidity. Because drying oils are saponified by alkalies, they should not be applied to alkaline surfaces, including applications over galvanizing (as a result of the alkaline nature of zinc hydroxide, a corrosion product of zinc), concrete, mortar, and most cementitious surfaces (as a result of inherent alkalinity because of the use of lime as a component of cement).

c. Alkyd modification (oxidative). Alkyds are perhaps the most widely used industrial protective coating by virtue of their ease of application, relatively low cost, color stability, and good weather ability in most atmospheric environments; therefore, it is reasonable to assume that coating formulators would seek to improve properties of the drying oil alkyd by

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