

Thin-film powder coatings: Design and application issues

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This is the second article in a three-article series on issues to consider in thin-film powder coating applications. The article discusses the important performance criteria and specifications that have to be met for successful thin-film applications. While the first article, published in the February issue, is directed primarily at the powder coatings end user, this article is of equal importance to powder coatings formulators, manufacturers, and end users.

The third article in the series, which will be published in a later issue, deals with the application of thin-film powder coatings. Although it primarily addresses the end user, it will also interest powder coatings formulators and manufacturers.

The application of coatings at film thicknesses thinner than 1.2 mils (30 microns) can be tried with virtually every powder coating on the market. For the best results, however, formulators, manufacturers, and end users, or applicators, should discuss and evaluate issues such as design, formulation, application, and end use for the best possible performance and economy of any given thin-film powder finish.

One decisive factor in successful thin-film application involves the correlations between the color and the opacity of the pigmentation of powder coatings, which can indicate problem colors for thin-film application. Other factors include pigment-filler and substrate wetting, the choice of powder coating systems and chemistries, the particle size distribution of the powder coating, and the smoothness and shape of the substrate.

Color and thin-film application: Problems with hiding

An appearance issue, hiding, or how well a coating prevents the substrate from showing through, involves the color difference between the coating and the substrate, color and pigment concentration, saturation, and transparency, or opacity.

The closer the substrate color is to the coating color, the higher the hiding capability of the coating and vice versa. For example, a black coating applied at varying film builds on black-white contrast hiding charts can give the impression of excellent hiding power on the black substrate but appear in shades of dark gray on the white side of the chart. Most metal substrates have a grayish color, and some pretreatments can change the substrate to a yellowish or a bluish color. Powder coatings, however, appear in all shades and colors.

Dark colors usually hide very well, even at low film builds. The amount of colorants can be kept relatively low, which means the specific gravity of a thin-film powder coating can typically be kept within 1.25 and 1.50. White and pastel colors, however, require high pigment concentrations (mostly white) for hiding around 1 mil (25 microns). The specific gravity of such systems is higher than it is for dark colors, commonly 1.80 to 1.85. Brightly colored powder coatings containing mostly organic pigments as colorants can be more problematic for thin-film application. Often, the necessary opacity is difficult to achieve at reasonable costs.

The following guidelines may help powder coatings formulators and end users make decisions about which col-

ors are more suitable than others for thin films. Using the Lab color system² (see Figure 1), thin-film application for colors moving along the L axis (black-white) don't create insurmountable problems. High pigment amounts (generally more than 45 percent per total formula), that is, high specific gravities, are necessary for white and tinted white shades. Pigment amounts and specific gravities decrease with lower L values, moving from white to gray to black.

Colors in the -a (green) and -b (blue) area, -a/-b (blue-green), or on the blue side of +a/-b (reddish-blue, purple), usually hide well at thin film builds in the presence of (some) white pigment. In the absence of white pigments, reddish-blue, blue, blue-green, and green pigments are often quite dark. As a result, they appear opaque.

However, the situation becomes more critical in the +a (red), +b (yellow), and the +a/+b (orange) region of the Lab color coordinates. Highly saturated yellow, orange, and bright red shades are often quite transparent at film builds of 1.2 to 1.5 mils (30 to 38 microns). These colors aren't very suitable for thin-film applications. However, some clear, or transparent, powder coatings are applied at thin films on special substrates, for example, bathroom fixtures.

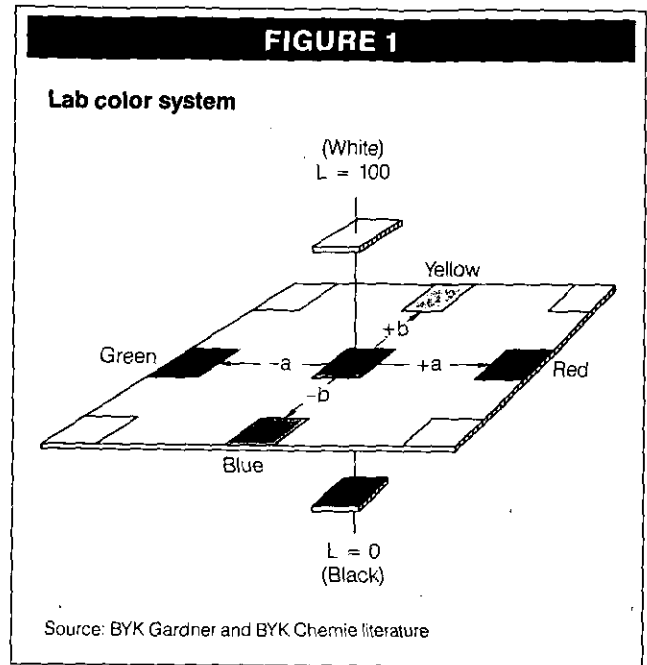
Thin-film application: Design and formulation

As previously mentioned, virtually every powder coating can be formulated for thin-film application. However, not all powder coatings and chemistries are equally suitable for it. Because very good flow and leveling are prerequisites for thin films, powder coating formulators should start off by selecting resins with low viscosities³. Another way to modulate the viscosity, or the surface tension⁴, of powder coatings is to use some specialty additives, such as surfactants⁵. These additives will help wet out substrates, as well as pigments and fillers, which is important especially in highly pigmented coatings.

The following equation, called the *Washburn equation*, shows the inverse relation of wetting speed (of fillers and pigments) and viscosity: The higher the viscosity, the slower the wetting speed. This is important, especially for highly filled powder coating systems. Poor or incomplete pigment-filler wetting results in inert⁶ agglomerates, which can cause protrusions (seeding) and cratering, especially in thin films. Using pigment-filler wetting and dispersing agents, combined with low resin (or binder⁷) viscosity, certainly makes good sense here.

Washburn equation

$$v = K \times \gamma_{FL} \times \cos \theta \times \frac{r^3}{l \times \eta}$$



Where

v = wetting speed

K = constant

γ_{FL} = surface tension of the liquid phase

θ = contact angle

r = radius of the pores

l = length of the pores

η = viscosity of the liquid phase

$\gamma_{FL} \times \cos \theta$ = spreading pressure

To achieve good substrate wetting, the liquefied powder coating must have a surface tension equal to, or lower than, the substrate. Good substrate wetting is indicated by a low contact angle θ as seen in Figure 2. Wetting is poor when the contact angle is high, for example, 90 degrees.

Figure 3 shows in very schematic form what happens when you apply one layer of powder in 30-micron particle size on a substrate. To achieve 1-mil (25 microns) film thickness, the particles can barely be touching (Figure 3a). Excellent substrate wet out, preferably combined with low binder viscosity, lets the particles flow out and creates a more or less uniform film (Figure 3b). Poor flow, a texturelike film surface, and possibly some exposed substrate can result in poor substrate wet out, especially when combined with higher binder viscosity or thixotropy^{8,9} (Figure 3c).

Different substrates have different surface-tension characteristics. This means that a specific powder coating

can be applied very well as a thin coating on some substrates (and pretreatments) and not so well, or not at all, on others. The formulator should know the type and pretreatment of a substrate to design and formulate the correct wetting characteristics of the powder coating.

A drawback in choosing lower viscosity resins, or viscosity modulation, is the possibility of a decrease in the powder coating's glass transition temperature¹⁰ (T_g). This could negatively affect storage (sintering) stability or application performance (impact fusion, edge coverage), especially because finer particle size distributions are required for thin-film powder applications with corona-charging spray guns than for other applications.

Thin-film application: Suitable powder coating chemistries

Several powder coating chemistries are fitting candidates for thin-film applications. These include epoxies, hybrids, polyesters, and acrylics.

Epoxies. These are quite suitable for thin-film application. Specially formulated phenolic-cured systems can be of some interest here. They combine excellent flow and leveling, good overall properties, and low bake temperatures (as low as 300°F, or 149°C).

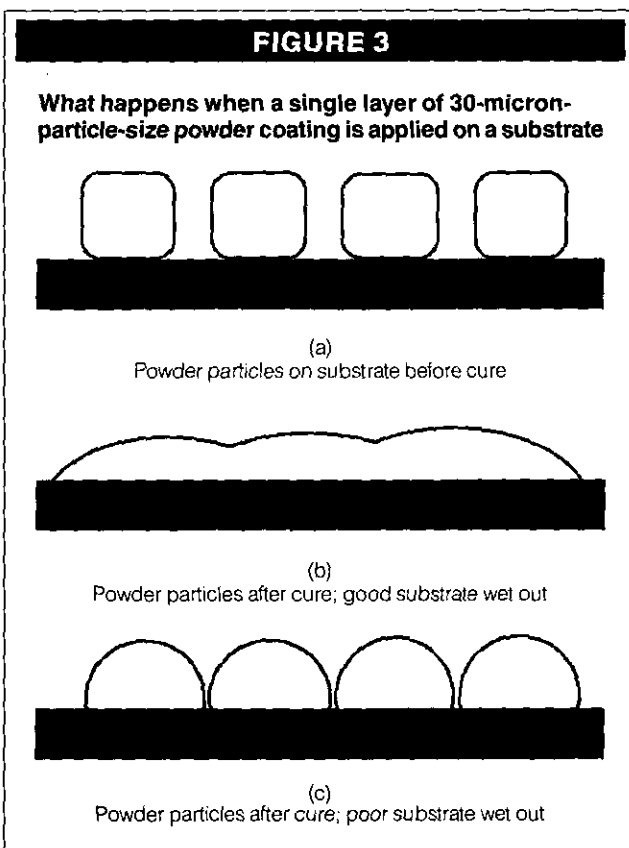
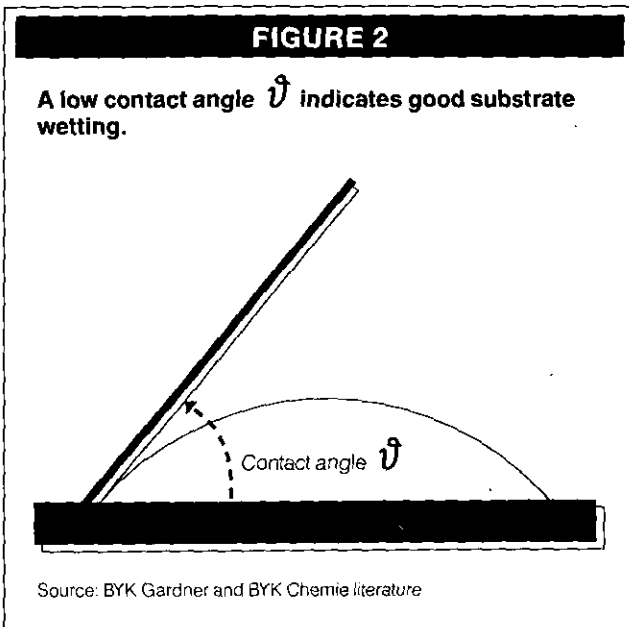
Hybrids. Carboxy polyester/epoxy hybrid systems can be formulated for and applied as thin films. However, some hybrids can show higher rates of film defects than others. These defects include orange peel, dimples, or even craters, especially in the presence of minor airborne or line contamination. Moreover, these hybrids' usually higher transfer efficiency when compared with other chemistries makes them more difficult to apply in thin films.

Polyesters. Urethane based. Polyester urethane, or polyurethane, powder coatings are close to ideal for the application of thin films. Excellent flow and leveling properties, combined with the possibility of choosing resins with varying hydroxyl numbers (low or high functionality), make them very versatile systems that can meet numerous physical and chemical specifications. Blocking-agent-free (free of E-caprolactam, or E-cap) polyurethanes can be formulated for thin-film application. Even though polyurethanes show good-to-excellent weathering properties, using thin films outdoors isn't recommended for reasons that will be explained later in the article.

TGIC based. Although smooth polyesters based on TGIC (triglycidyl isocyanurate) are available or can be formulated for thin films, they aren't an ideal solution for this purpose. High transfer efficiencies make it more difficult to apply them at thin film thickness. In addition, what was said about weathering regarding polyurethanes goes for TGIC systems as well.

HAA based. The suitability of polyester powders based on HAA¹¹ (hydroxyalkyl amide) for thin-film application is similar to TGIC-based systems.

TMMGU based. Hydroxyl polyester/TMMGU (tetramethoxymethyl glycoluril) combinations¹² show great



promise for thin-film application because of their superb flow and leveling properties and adjustable reactivity (controlled by acid catalysts). However, the low T_g of many of these systems, combined with finer particle size, makes storage and application more problematic because of higher probabilities for sintering and impact fusion. Here again, the restrictions mentioned about weathering apply to these systems.

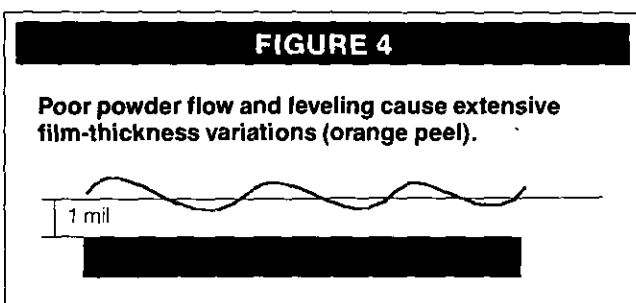
Acrylics. Weathering restrictions apply for acrylics in general, but the flow and leveling properties of GMA (glycidyl methacrylate) acrylics encourage the application of thin films, particularly in multicoat finishing, that is, automotive basecoat-topcoat systems.

Thin-film application: Less suitable powder coating chemistries

Thin powder coatings may not be advisable, or feasible, for meeting certain requirements or specifications. Warning flags should go up when thin-film powder coatings are considered for the following applications, conditions, or environments.

Low-temperature cure. These systems, typically 250°F to 300°F (121°C to 149°C), are, by nature, very reactive. The high reactivity doesn't allow the powder particles to flow out very well during cure before the thermoset reaction takes place. Unless the viscosity of the formulated powder is already very low at the intended cure conditions, either by resin design or by viscosity-reducing additives use, the conditions will inhibit good flow and leveling of the powder coating. As a result, the films will show a pronounced orange peel, or texture.

It's easy to see (in Figure 4) that an orange peel-like finish of an average 1-mil (25 microns) thickness can fluctuate between 0.5 mil (13 microns) in the valleys and 1.5 mils (38 microns) at the peaks. This can cause problems in coating appearance and performance, such as hiding and reduced physical and chemical properties. Moreover, a reduction in resin or formulated powder viscosity can reduce the T_g , which leads to sintering or impact-fusion problems.



Chemical, corrosion, and electrical protection. Thin-film powder coatings used for chemical resistance, corrosion protection, and electrical insulation aren't recommended. The probability of film porosity, that is, pinholing and microcratering, is very high. This can be caused by film thickness fluctuations, substrate roughness, or small film contaminants—such as microscopic dirt and dust, small gelled particles, pigment-filler agglomerates, or coarse pigment-filler particles. Substrate and film destruction (film delamination) are virtually immediate in such cases. Film builds of 2 mils (50 microns) or thicker are usually required to meet higher resistance and insulation specifications.

Abrasive environment. A caution flag should be raised for thin-film applications on products subjected to an abrasive environment. These products include power tools, telecommunication equipment, manufacturing machinery, and some appliances. Even though highly abrasion-resistant coatings can be applied at around 1 mil (25 microns), abrasive actions, such as continuous handling, cleaning, or materials contact, can easily remove 0.2 mil (5 microns) of film per year—or even more. This means that a thin film could become worn enough to be ineffective after only a couple of years, which wouldn't be satisfactory for the customers of the equipment (see Figure 5).

Outdoor exposure. Thin-film application of weatherable powder coatings destined for outdoor exposure should be discouraged. It has been documented that powder coatings exposed outdoors lose from 0.04 to 0.12 mil (1 to 3 microns) of film thickness per year because of binder deterioration and abrasion through ultraviolet-light radiation, wind, rain, and dust. Figure 5 shows film losses from abrasion and weathering for coatings of 1 mil (25 microns) and 2 mils (50 microns) at loss rates of 0.04, 0.12, and 0.2 mil (1, 3, and 5 microns) per year. Obviously, any coating has to be designed to last as long as the intended service life of the parts it covers.

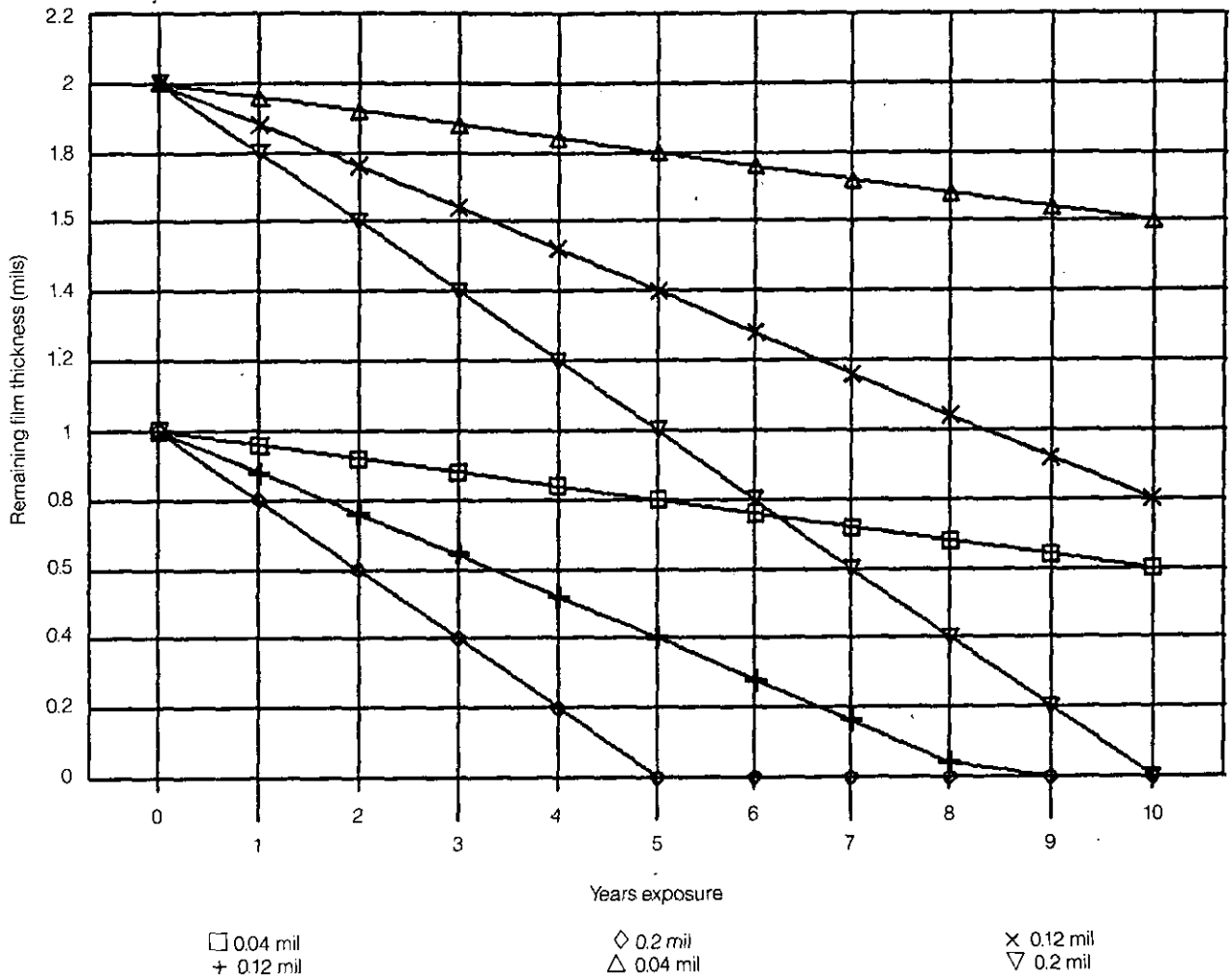
Textures. Finally, textured powder coatings are generally unsuitable for thin-film applications because the texture itself can show thickness variations of 1 mil (25 microns) or more.

Thin-film application: Particle size distribution

Based on conventional wisdom and industry experience, the medium particle size of a regular decorative powder coating should be around 35 to 40 microns (1.4 to 1.6 mils) for applications of 1.5 to 4 mils (38 to 100 microns) using coronacharging spray guns. Ultrafine particles (under about 8 microns, or 0.3 mil) are usually cut out, or scalped, to prevent poor flow, fluidization, and impact fusion. Figure 6 shows a distribution curve for a regular decorative powder coating.

FIGURE 5

Film-thickness loss through abrasion and weathering



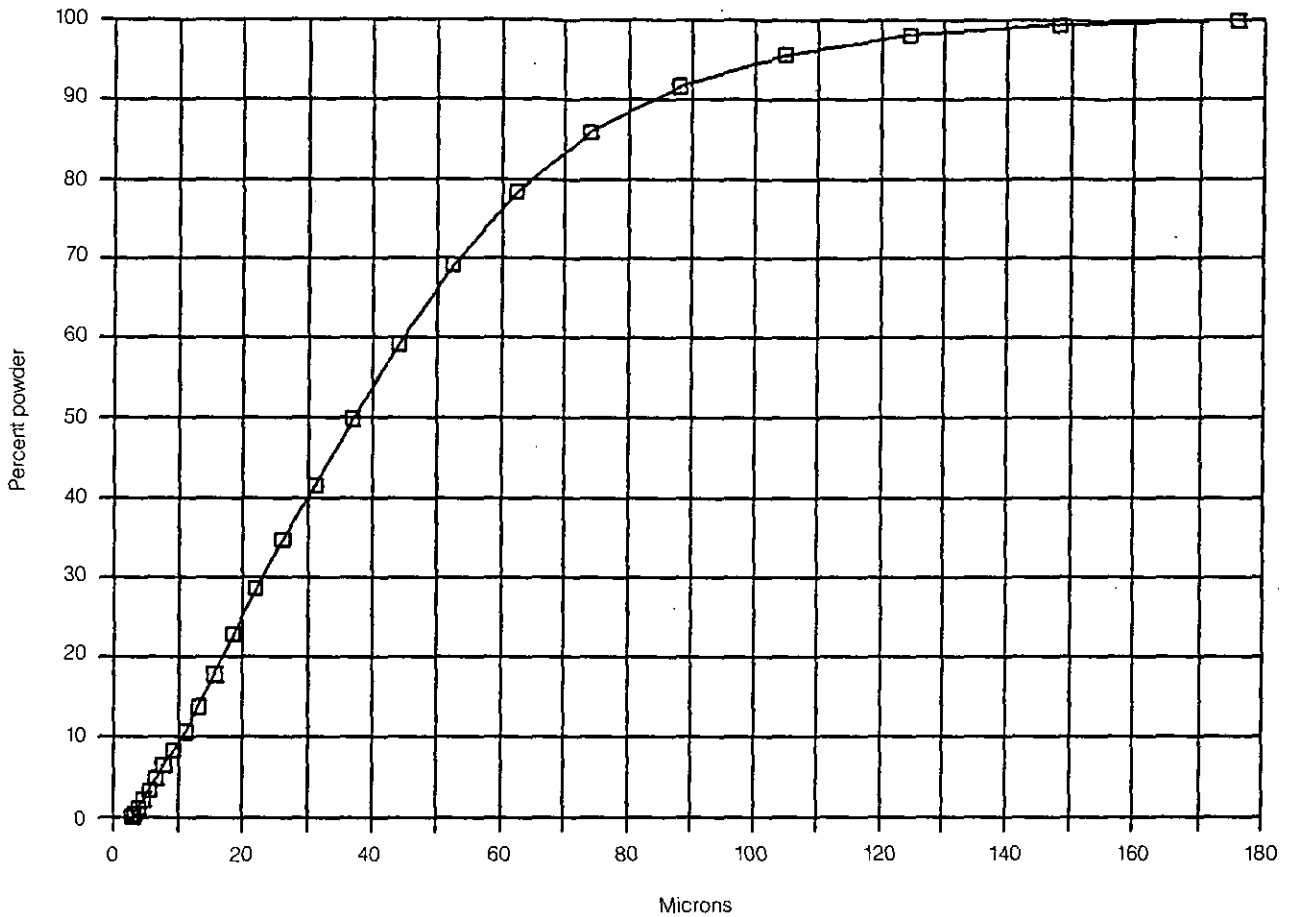
From a theoretical point of view, any particle larger than 75 microns (3 mils) may not flow out completely during the cure cycle of a film that is 1 mil (25 microns) thick, which results in some kind of textured (orange peel-like or protrusive) appearance. This problem has resulted in the following rule: The largest powder particles shouldn't be much larger than twice the intended film thickness for applications of coatings thinner than about 1.2 mils (30 microns). Figure 7 shows a distribution curve for thin-film powder coatings.

The control over the correct particle size distribution for thin-film applications rests solely with the powder coatings manufacturers. But it's understood that their efforts to control powders with finer grind sizes (for example, more sophisticated formulations, longer grind time, special postadds, higher manufacturing losses) could demand some premiums for such products. The calculations about the advantages of thin-film applica-

tion in the first article in this series don't reflect all these manufacturing variables.

Thin-film application: Substrate choice

You can apply a general rule when it comes to thin-film application and substrate type: The coarser and more porous the surface of the substrate, the thicker the coating should be and vice versa. You should consider thin-film powder coatings only for smooth, nonporous substrates. It seems obvious that thin-film application on cast iron/steel surfaces or steel that is blasted with abrasives (sand, grit, aluminum oxide) is essentially nonsensical. During cure, the melting powder puddles in the substrate valleys and leaves the peaks uncoated and exposed (see Figure 8). Porous substrates can show outgassing from entrapped air during cure. This air can become trapped in the semicured coating and turn the

FIGURE 6**A particle size distribution curve for a regular decorative powder coating**

coating into a thin foam, which reduces the protective properties of the coating.

The capability of the liquefied powder to wet out the substrate is a key element in thin-film application, as discussed previously. Formulators can modify the surface tension of the liquefied powder by adding surfactants to promote better substrate and pigment-filler wet out. However, certain difficult substrates, such as galvanized steel or terne plate, will often cause problems for powder coating application at any film build.

You should also consider the substrate shape. During the first part of the cure cycle when the applied powder liquefies (but before crosslinking), the liquid film tries to pull away from sharp edges. Low resin viscosities and the use of some surfactants, commonly found in thin-film powder coatings, enhance this phenomenon further (see Figure 9). A formulator work-

ing on improving poor edge coverage by speeding up the cure or increasing the thixotropy of a thin-film system may end up impairing film flow and leveling. Here again, thin-film powder coatings are more suitable for flat or slightly rounded parts or parts that lack sharp edges.

Summary

Certain colors are more suitable for thin-film application than others because they provide better hiding. Opacity problems can show up for yellow, orange, and red colors. Low binder viscosities are advantageous for designing thin-film powder coatings. The surface tension of the liquefied powder should be equal to or lower than the substrate surface tension.

Virtually all powder coating chemistries can be formulated for thin-film application. Polyurethane systems

FIGURE 7

A particle size distribution curve for a thin-film powder coating

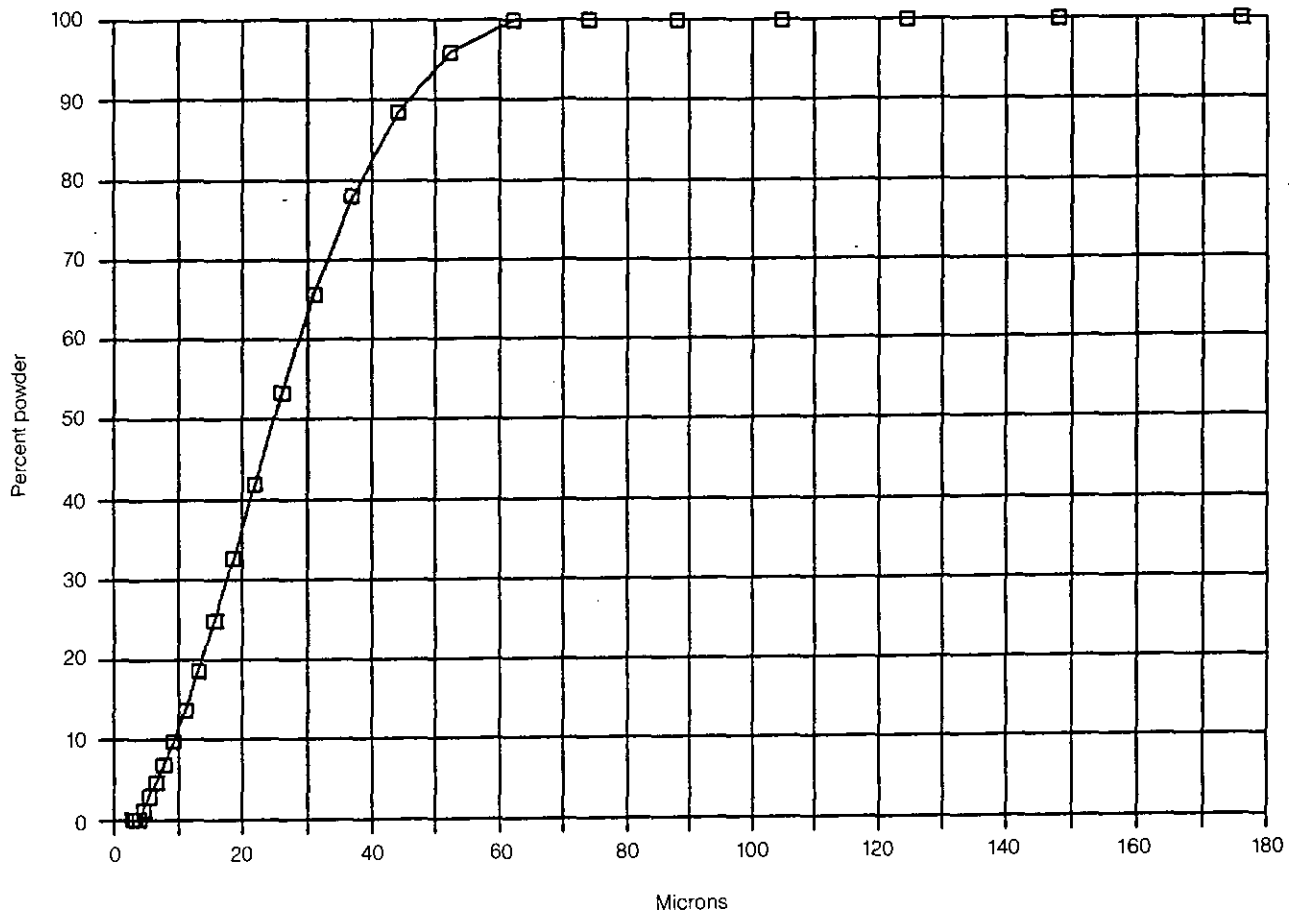


FIGURE 8

Film-thickness variations of a powder coating on a coarse substrate



may be specially suited because of flow, physical properties, and cost. Thin-film application is less suitable or not recommended for the following conditions or specifications: low-temperature cure, above-average chemical resistance, above-average corrosion protection, good electrical insulation, abrasive conditions or environments, long-term outdoor durability, and textures.

The particle size distribution of the powder has an influence on its applicability as a thin film. As a gener-

FIGURE 9

The effects of viscosity/thixotropy on edge coverage



Good edge coverage
(high viscosity/thixotropy)

Poor edge coverage
(Low viscosity/thixotropy)

al rule, finer powders are needed for lower film builds, but superfine particles can cause problems in the application process. Substrate smoothness, wetting, and

shape are important issues in thin-film powder coating application. **PC**

farbe+lack, 86, August 1980, pp. 696-698.

End notes

1. Organic pigments. Colorants with a carbon-based backbone. Typical examples are phthaloblue, phthalogreen, quinacridone red, and azo pigments. Inorganic pigments, on the other hand, are often metal oxides, such as iron oxide red, nickel titanium yellow, and titanium dioxide.
2. Lab color system, or CIE 1976 L*a*b* color space. A uniform color space that uses an Adams-Nickerson cube root formula, adopted by the International Commission on Illumination in 1976 for measuring small color differences. Definition from *A guide to Understanding Color Communication* (Grandville, Mich.: X-Rite, 1993).
3. Viscosity. The property of resistance to flow in a fluid. Examples for low, medium, and high viscosities are water, engine oil, and molasses.
4. Surface tension. Cohesive force between a liquid and a dry surface.
5. Surfactants. Surface-tension modifiers.
6. Inerts. Generally pigments, fillers, and some additives, which don't take part in the chemical cure reaction.
7. Binder. Resins and curatives; the cement, or glue, that binds the inerts together in a film.
8. Thixotropy. The property exhibited by certain gels in becoming liquid when stirred or shaken. Definition from F.C. Mish, editor-in-chief, *Webster's Ninth New Collegiate Dictionary* (Springfield, Mass: Merriam-Webster, 1990). The reverse holds true as well: Thixotropic behavior of a liquid, or liquefied, coating prevents dripping and sagging because of the gel-like nature of the coating.
9. For additional and more detailed scientific information about substrate wetting and film formation, please consult the following paper: Douglas S. Richart, "Powder Coating: Current Developments, Future Trends," presented at the Waterborne, High Solids, and Powder Coating Symposium, Feb. 22-24, 1995.
10. Glass transition temperature (T_g). The virtual cessation of molecular motion on a molecular scale for any organic polymer material at temperatures below the T_g . At temperatures just above the T_g , the molecular motion causes stickiness on the surface of the polymer materials, which leads to lumping and sintering of these products.
11. Primid XL-552, a trademark of EMS-American Grilon.
12. Powderlink 1174, a trademark of Cytec Industries.

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