Powder Coating Technology

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by

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Foreword

This book provides an overview of the current status of powder coating technology. Powder coating use in North America is increasing at a rate approaching 20% per year in terms of quantities of powder sold. Recent improvements in the technology required to manufacture and apply powder coatings, in conjunction with environmental considerations, have led to this rapid growth. Many of the drawbacks previously associated with the use of dry powder coatings as an industrial finish have been virtually eliminated. As a result, there are currently about 2,000 powder coating operations in the United States and the number is increasing rapidly.

Because powder coatings are applied as dry, finely divided particles, there are no volatile organic compounds (VOCs) released during the curing application, and only minute quantities are released during the curing process. Therefore, the increased use of powder coatings, as an alternative to liquid solvent-based coatings, represents a significant reduction in emissions of VOCs.

The book describes current powder coating materials and equipment, end uses, and economic advantages of the use of powder coatings. Included are discussions of the disadvantages and potential problems identified early in the powder coating development process, as well as possible resolutions of many of these problems.

The information in the book is from *Powder Coatings Technology Update,* prepared by Charles I. Hester and Rebecca L. Nicholson of Midwest Research Institute and Margery A. Cassidy of C-Tec, Incorporated for the U.S. Environmental Protection Agency, October 1989.

The table of contents is organized in such a way as to serve as a subject index and provides easy access to the information contained in the book.

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NOTICE

Contents and Subject Index

1. Introduction

The purpose of this report is to provide an overview of the current status of powder coating technology. Powder coating use in North America is increasing at a rate approaching 20 percent per year in terms of quantities of powder sold.[1] Recent improvements in the technology required to manufacture and apply powder coatings, in conjunction with environmental considerations, have led to this rapid growth. Many of the drawbacks previously associated with the use of dry powder coating as an industrial finish have been virtually eliminated. As a result, there are currently about 2,000 powder coating operations in the United States and the number is increasing rapidly.[2]

From an environmental standpoint, the increased use of powder coatings as an alternative to liquid, solvent-based coatings represents a significant reduction in emissions of VOC's. Because powder coatings are applied as dry, finely divided particles, there are no VOC's released during application and only minute quantities are released during the curing process. Therefore, the use of powder coatings as a means of reducing VOC emissions from industrial finishing operations is being encouraged by many air pollution control agencies. This report is intended to be helpful to those agencies by providing them information regarding the types of products being powder coated. It is anticipated that this will assist them in evaluating powder as a recommended air pollution control technology by answering questions concerning the performance, applicability, costs, and availability of powder coatings.

The information presented in this report is based on data obtained from literature searches, contacts with several State and local air pollution control agencies, and written survey questionnaires. Survey questionnaires were submitted to nine powder coating equipment suppliers, nine powder coating manufacturers, and nine powder coating users. Three of the nine equipment suppliers responded, and a summary of their responses is presented in Appendix A. A summary of the responses from the seven powder coating manufacturers who took part in the survey is presented in Appendix B. Four powder coating users responded and that summary is contained in Appendix C.

The remainder of this report is divided into five sections. The first provides a brief history of powder coatings from the 1950's through the 1980's. The next section describes the different classes of powder coatings that are currently available, including those types of powder resins that have recently been developed. The types of equipment required for a powder coating line and the types of products that are typically powder coated are discussed in Sections 4 and 5. A list of representative products currently being powder coated is also included in Section 5. Section 6 discusses the economic advantages of using powder coatings and presents a cost comparison between powder and liquid coatings. Section 7 presents the major points discussed in this report and conclusions.

2. Background

The technology for finishing metal products with dry powder coatings rather than with conventional liquid paints has been available in this country since the mid 1950's. By the late 50's, powder was being used to coat pipe for corrosion protection and electric motor parts for insulation. These coatings were applied using a fluidized-bed process in which heated parts were dipped into a vat containing powder suspended in air. In this process, once the particles of powder contact and adhere to the heated metal parts, they begin to soften and flow into a smooth, even layer. Most of the coatings applied in fluidized beds were vinyl or epoxy powders. Typical coating thicknesses ranged from 150 to 1,000 μm (6 to 40 mils) and the applied coatings were functional rather than decorative.[3]

During the historical development of powder coating technology, there were several disadvantages or potential problems identified. Today, most of these have been resolved or minimized. The following are some of the major issues that were problems in the past:

1. Frequent color changes could entail extensive downtime for production lines and the ability to apply a wide range of colors could be restricted by equipment requirements and changeover times. Multiple booths are required for rapid color changes and special equipment is required to recover different colors separately (for recycle).

2. Storage and handling of powder requires special "climate" controls; powder will not remain "fluid" if exposed to moisture.

3. Accurate feeding of powder to the spray gun might be difficult, resulting in uneven flow.

4. Color matching and color uniformity appear to be more difficult to achieve than with liquid coatings.

5. Uniformity of coating thickness is sometimes difficult to maintain and thin films 25 to 51 μm (1 to 2 mils) are sometimes difficult to achieve.

6. Cure temperatures required for some powders are so high that damage may occur to solder joints or temperature-sensitive parts of the item being coated. High cure temperatures and long cure times require high fuel usage.

7. Powder coatings are especially susceptible to "Faraday cage" effects on sharp internal corners.

8. Airflow in the booth and the area prior to the oven must be carefully controlled to avoid dislodging the unbaked powder.

9. Because of the extra equipment requirements (multiple booths, powder handling and recovery systems), conversion of an existing liquid line could be very expensive.

Technological advances in powder coating have addressed most of these issues. These advances are discussed in this report.

The development that opened the way for powder coatings to become a major factor in the metal finishing industry was the introduction of the electrostatic spray process in the early 1960's. Electrostatic spraying of powders allowed the application of relatively thin layers of coatings and allowed powders to be used on parts not suitable for dipping in a fluidized bed. Thus, powder coatings became a viable alternative for decorative as well as functional coatings.

The emergence of powder coatings as an alternative to liquid decorative coatings led to the development of a variety of resin systems designed to meet the needs of the diverse user industries. Epoxy resins were used almost exclusively during the early years of powder coatings. Polyesters, polyester/urethanes, acrylics and (most recently) polyvinylidene fluoride, have now become equally accepted resin systems, with each having its own market share depending on the performance characteristics needed for the product. Powder coatings currently are available in virtually any color, gloss level, and texture.

Recent advances in application technology also have allowed powder coatings to be used in an increasing number of industries. Automated finishing systems that allow rapid and frequent color changes and extremely high powder utilization efficiencies have made powder an economical coating in many high-volume industries. (Powder utilization efficiency is defined as the percentage of purchased powder that is deposited on the work piece [including any powder that is recovered and resprayed].)

3. Powder Coating Materials

As recently as the early 1970's, the powder coating industry had a limited number of solid resin systems on which to base their powder formulations. Consequently, the ability of the powder coating industry to meet the diverse needs of the finishing industry was also limited. Because of the increased concerns over VOC emissions, worker safety, and energy costs during the 1970's, the popularity of powder coatings grew until powder coatings represented 8 percent of coating used in the finishing industry by 1987.[4] As the interest in powders grew, the industry responded with technological improvements in the resins and with many new resin systems. Powder coatings are now formulated in a virtually limitless range of colors, glosses, and textures. The two major types of powder coatings, thermoplastics and thermosettings, are discussed below.

3.1 THERMOPLASTIC POWDERS

A thermoplastic powder coating is one that melts and flows when heat is applied, but continues to have the same chemical composition once it cools and solidifies. Thermoplastic powders are based on high molecular weight polymers that exhibit excellent chemical resistance, toughness, and flexibility. These resins tend to be difficult to grind to the consistant fine particles needed for spray application, and they have a high melt viscosity. Consequently, they are used mostly in thicker film applications and are applied mainly by the fluidized bed application technique.

Typical thermoplastic powder coatings include: polyethylene powders, polypropylene powders, nylon powders, polyvinyl chloride powders, and thermoplastic polyester powders. Polyethylene powders were the first thermoplastic powder coatings to be offered. They provide excellent chemical resistance and outstanding electrical insulation properties. Polyethylene coatings are smooth, have a medium gloss, and good release properties that allow sticky materials to be cleaned from their surfaces. They are often used as coatings for laboratory equipment. Polypropylene powder produces a surface that is very inert and is often used in applications where the powder-coated part may be exposed to chemicals. Nylon powders offer excellent abrasion, wear and impact resistance, and a low coefficient of friction. They are commonly used as mechanical coatings for sliding and rotating bearing applications in appliances, farm equipment, and textile machinery. Polyvinyl chloride powders provide good durability as well as flexibility. An example of products coated with polyvinyl chloride powders is dishwasher racks. Thermoplastic polyesters offer good exterior durability and weatherability. They do not usually require a primer for good adhesion to most metals and are often used for outdoor metal furniture.

Thermoplastic powders are especially well suited for a thick coat capable of extreme performance requirements. Because of the inherent thickness of these coatings, they do not generally compete in the same market as liquid paints.

3.2 THERMOSETTING POWDERS

Thermosetting powder coatings are based on lower molecular weight solid resins. These coatings melt when exposed to heat, flow into a uniform thin layer, and chemically cross-link within themselves or with other reactive components to form a higher molecular weight reaction product. The final coating has a different chemical structure than the basic resin. These newly formed materials are heat stable and, after curing, do not soften back to the liquid phase when heated. Resins used in thermosetting powders can be ground into very fine particles necessary for spray application and for applying thin, paint-like coatings. Because these systems can produce a surface coating that is comparable to, and competes with, liquid coatings, most of the technological advancements in recent years have been with thermosetting powders.

Thermosetting powders are derived from three generic types of resins; epoxy, polyester, and acrylic. From these three basic resin types, five coating systems are derived. Epoxy resin-based systems are the most commonly used thermosetting powders and are available in a wide range of formulations. They are used for both functional and decorative coatings. Functional properties of epoxies include corrosion resistance and outstanding electrical insulation. Decorative epoxies offer attractive finishes that are tough, corrosion resistant, flexible, and have high impact strength. These lack ultraviolet resistance and therefore, are not recommended for outdoor use in direct sunlight because of their tendency to chalk and discolor. High chemical reactivity and the use of various classes of hardeners are opening a wide range of applications for epoxies. Recent developments allow epoxies to be cured at temperatures as low as 121°C (250°F) for 20 to 30 minutes, or even shorter times at higher temperatures.[5]

Epoxy-polyester hybrid coatings consist of epoxy and polyester resins. These coatings are used mainly for decorative applications. They are more resistant to chalking and yellowing than epoxies but have a lower surface hardness and are less resistant to solvents.

Polyester-TGIC coatings contain a polyester resin cross-linked with triglycidyl isocyanurate (TGIC) as a curing agent. These powders offer very good mechanical properties, impact strength, and weather resistance. They are resistant to chalking and are often used for such outdoor applications as patio furniture, lawn mowers, and aluminum extrusions and panels for large commercial buildings.

Acrylic-urethane coatings are formulated with acrylic resins crosslinked with blocked isocyanates. They have excellent color, gloss, hardness, weatherability, and chemical resistance. They have an excellent thin film appearance but are less flexible than polyesters.

Polyester-urethane coatings are formed by cross-linking polyester hydroxyl resin with blocked isocyanate hardeners. Polyurethanes have an outstanding thin film appearance and toughness as well as good weathering properties.

Tables 1a and 1b provide a summary of the key physical properties of the thermosetting powder coatings described above.

3.3 NEWLY DEVELOPED POWDERS

In addition to the coating types discussed above, new developments are occurring in the area of enamel powders. Conventional porcelain enamel, the glassy coating traditionally found on metal surfaces such as bathtubs and washing machines, is a vitreous inorganic coating bonded to metal by fusion. The porcelain enameling process involves the re-fusing of powdered glass on the metal surface. The powdered glass is formed by melting oxide components and then quenching to form enamel frits. The frits can be converted to wet sprayable suspensions or to dry enamel powders through ball-milling. The resultant enamel coating is heat stable to over 450°C (842°F), color fast, and scratch resistant.[7] Enamel

TABLE 1a. TYPICAL PROPERITES OF THERMOSETTING POWDER COATINGS[6]
(Metric Units)

Properties	Epoxy	Epoxy/polyester hybrid	TGIC polyester	Polyester urethane	Acrylic urethane
Application thickness	25-510 μm[a]	25-250 μm	25-250 μm	25-89 μm	25-89 μm
Cure cycle (metal temperatures)[b]	232°C-3 min 121°C-30 min	232°C-3 min 163°C- 25 min	204°C-7 min 154°C-20 min	204°C-7 min 177°C-17 min	204°C-7 min 182°C-25 min
Outdoor weatherability	Poor	Poor	Excellent	Very good	Very good
Pencil hardness	HB-5H	HB-2H	HB-2H	HB-3H	H-3H
Direct impact resistance, cm-kg[c]	92-184	92-184	92-184	92-184	23-69
Adhesion	Excellent	Excellent	Excellent	Excellent	Excellent
Chemical resistance	Excellent	Very good	Good	Good	Very good

[a]Thickness of up to 3,800 μm can be applied via multiple coats in a fluidized bed.
[b]Time and temperature can be reduced, by utilizing accelerated curing mechanisms, while maintaining the same general properties.
[c]Tested at a coating thickness of 51 μm.

TABLE 1b. TYPICAL PROPERITES OF THERMOSETTING POWDER COATINGS[6]
(English Units)

Properties	Epoxy	Epoxy/polyester hybrid	TGIC polyester	Polyester urethane	Acrylic urethane
Application thickness	1-20 mils[a]	1-10 mils	1-10 mils	1-3.5 mils	1-3.5 mils
Cure cycle (metal temperatures)[b]	450°F-3 min 250°F-30 min	450°F-3 min 325°F- 25 min	400°F-7 min 310°F-20 min	400°F-7 min 350°F-17 min	400°F-7 min 360°F-25 min
Outdoor weatherability	Poor	Poor	Excellent	Very good	Very good
Pencil hardness	HB-5H	HB-2H	HB-2H	HB-3H	H-3H
Direct impact resistance, in-lb[c]	80-160	80-160	80-160	80-160	20-60
Adhesion	Excellent	Excellent	Excellent	Excellent	Excellent
Chemical resistance	Excellent	Very good	Good	Good	Very good

[a]Thickness of up to 150 mils can be applied via multiple coats in a fluidized bed.
[b]Time and temperature can be reduced, by utilizing accelerated curing mechanisms, while maintaining the same general properties.
[c]Tested at a coating thickness of 2.0 mil.

powders, a potential replacement for porcelain, are presently available in a limited range of colors and are relatively expensive to manufacture. Continued development is expected to make these coatings more competitive.

Polyvinylidene fluoride coatings have recently become available in powder form.[8] These fluoropolymer powder coatings have been available in Europe for about 2 years and are now sold in the United States. Because of their high resistance to weathering, industrial pollution, and corrosion, they are used for exterior aluminum extrusions and panels for architectural purposes.

Advancements in powder coating formulations are occurring at a rapid pace. Powders are being developed to compete with almost every market that has traditionally been held by liquid coatings. Architectural coatings (based on fluoropolymers), heat resistant coatings, metallic and textured coatings, low-temperature-cure powders, transparent and clear powders, and powders that can be used to color plastic parts by introducing the powder into the mold used for compression-molded plastic are in production use at this time. Most of these developments have occurred during the last 4 to 6 years and most powder coating manufacturers believe that the potential of powder coatings is only beginning to be realized.