

Powder Coatings—Retrospect and Prospects

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POWDER coating¹ is a variation of powder metallurgy and consists of three stages: (i) preparation of the surface; (ii) application of the powder (a polymer); and (iii) its curing by fusion, applying heat. The conditions employed in these steps, such as high temperature required for curing, at present limit its uses to metal surfaces only. Though polyethylene powder was available for coating purposes as early as 1940, powder coating was tried in a big way only around 1952, following the introduction of the fluidized bed application technique^{2,3}. But the Z-blade mixers used then for manufacturing the powders required long dwell-time and high temperature. This caused melting of resins and made the production of powders of uniform particle size and shape difficult⁴. However, the adoption of the extrusion technique in the early 1960's changed the situation very much⁵. The dwell-time in these machines was so short that even the low molecular weight (~ 1500) prepolymers of thermosetting resins could be powdered satisfactorily. This kind of thermosetting epoxy resins became available in 1964 with the discovery of the hardening action of di-cyan diamide thereon⁶. The two chief defects—chalking (loss of gloss) and stringent curing conditions (200°C and 30 min), were rectified by using a more reactive substituted di-cyan diamide in the second generation epoxies⁷ in 1968. These developments brought a revolution in the powder coating technology and culminated in the relegation of the alkyd-melamine baking enamels⁸. Today, powder coating is deemed a breakthrough in the field of surface coatings, particularly for environmental protection.

Powder Materials

There are two important classes of powders—thermoset and thermoplast. The former do not normally require primers, though now-a-days primerless thermoplasts^{9,10} have also been developed; they have greater chemical and solvent resistance and improved flexibility-hardness relationships; and they are easy to handle⁶. The usual thermosets—the epoxies and now polyesters and polyacrylics also—can adhere to metallic surfaces and hence do not require primers. The greater chemical and solvent resistance of thermosets is due to their crosslinked condition. While crosslinking hardens the thermosets, the greater thinness with which thermoset films could be made ensures the required flexibility. Easier handling, such as lower application temperature of the thermosets, is due to the very low molecular weights of the prepolymer powders used initially⁶. However, for that matter, the edge coverage properties of the thermosets are poorer¹¹. The thermoplasts having high molecular weights do not flow off the edges and hence ensure a better coverage¹¹. The most important way of improving thermoplasts is the use of a blend of both thermoset and thermoplast to achieve the desired property balance. Though the first

powders were thermoplastic in nature, it was only the introduction of the thermosetting epoxies in the 1960's that really touched off the 'powder explosion'. The volume of production of the two classes of powders was the same till recently¹² and hopes were expressed that thermosets would outstrip their rival shortly. However, the emergence of sprayable primerless thermoplasts makes this forecast doubtful. The figures¹³ projected for the chief powders for 1977 are: epoxies, 25%; PVC, mainly thermoplastic, 22%; acrylic, 22%; polyester, 17%; polyethylene, 5%; nylon, 2%; and others, 7%. A comparison of these with the 1970 figures¹⁴ [epoxies, 33-41%; vinyls (PVC and PVA), 17-33%; polyesters, 8-10%; nylon, 3-10%; and others like polyethylene and cellulotics, 5-7%] shows a decline in the use of epoxies and nylon. The steep increase in the use of polyesters and the emergence of acrylics are particularly noteworthy. Thermoset polyesters and acrylics¹⁵ have reached the stage of commercial development. Cellulotics, polyesters and polypropylene have of late been prepared as sprayable thermoplastic powders¹¹. Polyurethane also is now available for powder coating.

Methods of Application

The two chief methods of application are: (i) fluidized bed dipping^{16,17}, and (ii) electrostatic methods¹⁸. In the former, there is a box with a porous substrate on the bottom containing the powder. When air or gas is forced from below through the powder, the powder gets fluidized. Metal parts, sufficiently preheated to melt the powder, are plunged into the bed and the molten powder, in the vicinity of the metal part, causes both adherence and flow-out of the resin. A water-quench afterwards provides a good gloss.

Electrostatic methods are essentially of two kinds: (i) fluidized bed¹⁶, and (ii) electrostatic spray¹⁹. In both, the particles are charged by friction. The charged particles are made to be attracted to metal objects by grounding them. The particles adhere to the surface and the film thickness becomes self-limiting owing to the insulation caused by the build-up of powder deposit⁴. But the fluidized bed method is somewhat more difficult to control. The spray method also has the drawback of overspray and without an attached reclamation unit, it is uneconomical. Fluidized beds are less suited than electrostatic spray for large three-dimensional objects due to the large volume of powders required, but have good capability of handling a large number of parts where complete coverage is desired²⁰. For that matter, it is difficult to coat parts with sharp corners and deep recesses by the electrostatic spray method, though it is easier to mask areas and to coat large surfaces²¹. Kestler²¹ attributes the growth of powder coatings to the electrostatic spray techniques only. It is well

adapted for the interior coating of pipes and tubes¹. In fluidized bed techniques, mostly the thermoplastic resins¹² are used, while the thermosets are considered better for electrostatic spraying. In the fluidized bed method, the thickness of the coat is 10-15 mils, whereas the electrostatic spray method gives a film of 1-4 mils only⁹. The fluidized bed-dip method and the spray method are, therefore, ideal for protective and decorative coatings respectively¹². Films obtained by the spray powder coating method come close to those obtained from solvent based finishes which have a thickness of 1-5 mils²². Powders (of cellulose-acetate-butyrate) for fluidized bed and electrostatic spray methods are 50 and 150 mesh respectively⁹. In terms of particle size, 52-340 μ has been recommended for the fluidized bed technique and 75 μ for the electrostatic technique^{23, 25}.

Characteristics of Powders²⁶

The size and size distribution of particles are perhaps the most important among the factors influencing powder coatings. In general, powders of small and uniform sized particles are difficult to obtain²⁷ and this is the reason why films resulting from powders are usually thicker than those of solvent-based paints³⁸. In ultrafine (below 1 μ) and superfine (1-10 μ) grades of powders, cohesive forces causing agglomeration are predominant. However, fine sized powders have got better throwing power and the resulting film has a smoother surface. If the size distribution of particles is wide, the performance characteristics are not very good. Harris²⁶ considers particles in the size range 10-100 μ as 'granular' and recommends granular particles of 20-30 μ size with a uniform size distribution in this range for powder coatings.

The shape of particles has a bearing on the flow and the charge accepting properties of powders. The ideal spherical shape is difficult to obtain, when the material is either intrinsically brittle, e.g. PVC, or when the resin has low molecular weight. Cryogenic and freeze extrusions are suitable methods for low and high molecular weight resins respectively. For intrinsically brittle materials, some lubricating additives are required additionally.

In completely dry powders, the cohesive forces are active, whereas in highly moist powders, the surface tension of water causes agglomeration. At about 0.4% moisture, the transport properties of powders are good, because at this level, water acts as a protective coating over the particles without its surface tension effects. Finely divided siliceous materials, if added at about 0.5% level, can improve the flow characteristics of highly moist powders. The well-known catalytic effect of water improves the curing rate of powder coatings and it is reported to enhance the charge acceptability also.

The electrostatic charge borne by the particles also influences the flow properties. Powders with resistivity above 5×10^{10} ohm-cm do not lose their charge easily and, therefore, can effect back-discharge. The charge-accepting properties of powders are chiefly decided by the additives present therein. Certain metallic oxides, for example, contribute to high resistivities of the order mentioned above. By mixing the oversprayed reclaimed powders with

fresh ones, the moisture and electrostatic charge build-up effects can be minimized. The comparatively drier nature of the particles of the oversprayed powders brings down the moisture content of the fresh powder. Fluidity depends upon density also. Higher density leads to improved flow characteristics. It requires a higher level of pigmentation, especially in the case of thin film powder coatings.

Uses—Present and Potential

Metal furniture, machine tools, signs, bus seats, vacuum cleaners²⁸ and sewing machines²⁹ are some of the well established areas for the application of powder coatings. One of the potentials is coating parts that are currently chrome plated^{28, 29}. The construction industry³⁰ and appliances³¹ are likely to be major consumers of powder coatings. The possible aircraft uses³¹ are on spline assemblies, drive accessories as coatings to reduce metal fatigue due to vibrational damping action, on leading edges to prevent abrasion and on composites to minimize void formation. The real contender, however, is the automotive industry. When the research presently conducted to apply the method to automotive finishes proves a success, powder coatings may enter a period of boom. At present, non-aqueous dispersion (NAD) has made considerable inroads into this area and it is passing through a phase of consolidation³². And so, even when the expected boom is fully realized, the share of powder coatings in 1981 is estimated roughly to be only around 11% of all finishes^{20, 33}.

Merits of Powder Coatings

Many of the solvents are toxic and their presence in air is inimical to eyes, vegetation and buildings³⁴. The contribution of surface coatings to the general air pollution is an important point. According to a 1961 survey carried out in Holland³⁵, it was 0.1% of the total pollution, whereas in California it is stated to be as high as 10%³⁶. The bad odour of the solvents causes quite a lot of local nuisance. The absence of solvents also reduces the fire hazard and eliminates solvent retention⁸.

The powders can be easily applied. Since these are in the ready-to-use condition, skilled labour needed for mixing, viscosity control, etc. is not required. Again, the fluidized bed and the electrostatic techniques make it incredibly easy to automate¹². Since the molecular weight of the polymers in film form is far greater than those of other paints, greater durability, toughness and abrasive resistance invariably result²⁸. In fact, powder coated materials have been shown to withstand rougher handling in transit to marketing centres. Also, there is no limitation on the selection of the polymer on solubility basis and hence the performance characteristics can be varied over a wide range. As there is no solvent, 100% utilization of the material is possible, making the economics also favourable¹⁴. As the coats are generally thicker, adequate covering can be achieved in one coat—a long cherished objective of surface coatings. No flash-off time from booth to oven is required¹⁰. Cleaning is simply by sweeping, vacuuming or even shaking, and this

is definitely easier than cleaning the equipment using solvent-borne material^{1,7,12}. Also, there is no need for demineralized water¹⁷.

Demerits of Powder Coatings¹⁸

The economics of spraying¹⁹ depends on the efficiency of reclamation of the spilt-over powder. In automatic sprays, this is 90% in the case of wire products and 70% in the case of sheet products. Straight filtering, using bags and cyclone filters are two standard methods of reclamation. Of these, cyclones with follow-up bag housings are more popular. But cyclones have the tendency to retain only coarser, larger and heavier particles, rendering the reconstitution of the powder with the original characteristics difficult.

High temperature of curing has a tendency to affect the white and pastel shades^{27,32}. Heat-sensitive substrates e.g. leather, wood, paper, etc. are unsuitable for powder coating.

Change of colour/powder or both¹² is a challenge to reclamation. In cases of frequent colour change, a separate system for each colour is recommended. Colour matching also presents a problem. The spray drying method is under investigation for this purpose³⁰. Resins suitable for powder coatings and in desired colours (especially metallic ones⁴¹) are somewhat rare as compared to wet paints.

Size constitutes another big problem. Large sized and three-dimensional objects are less fit than large sized two-dimensional ones for powder coating. For large three-dimensional objects, the electrostatic method is better.

Gloss is dependent upon the smoothness of the finished surface. Excessive drying time about reduction in the gloss is one of the major problems in powder coating.

Sharp-edge-coverage^{2,3,12}. The shorter curing time may leave some un-cured air in the film. This makes the surface rough. It is a primary texture effect usually superimposed over the secondary texture and has also a deleterious effect on the gloss. The faster curing increases the line speed; therefore, the recapitulation of faster curing, while enhancing line speed and sharp-edge-coverage, invariably impairs the gloss. By proper choice of hardeners, a compromise can be struck for optimum results in respect of thermosetting resins. In the case of thermoplastics, the same is secured by the choice of a suitable temperature. Nonetheless, cured films of powder coatings do not exhibit a clear layer of resin at the resin/air interface, as solvent-based finishes do⁴¹.

Future Trends

Some of the future trends according to Harris¹⁵ are: (i) replacement of the electrostatic gun in large automatic plants by a modified form of electrostatic fluidized bed; (ii) use of cryogenic methods of fine grinding in powder manufacture; (iii) development of resins of higher molecular weights and higher melting points with increased speed at higher temperatures; (iv) use of entirely resinous hardener systems; and (v) development of a powder that can

be coated in 1-4 mils thickness with good weatherability¹¹. In conclusion, it may be stated that the huge volume of activity in this field as evidenced by the large number of papers⁴³⁻⁴⁵ published and patents⁴⁶ taken promises bright prospects for the powder coating technology.

Summary

Various materials used for preparing the powders for use in powder coating practice, the methods of their application and their characteristics are described. The recent applications to which these powders are being put are outlined. The merits and demerits of their use are discussed. Future trends in the utilization of powder coatings are also forecast.

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