POWDER coatings are a variation of powder metallurgy and consist of three stages: (i) preparation of the surface; (ii) application of the powder (powdered thermoset); and (iii) 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. 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 difficult. However, the adoption of the extrusion technique in the early 1960's changed the situation very much. The dwell-time in these machines was so short that even the low molecular weight (ca. 1500) prepolymer 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 dicyanamide therein. The two chief defects choking (loss of gloss) and stringent curing conditions (200°C and 30 min), were rectified by using a more reactive substituted dicyanamide in the second generation epoxies in 1968. These developments brought a revolution in the powder coating technology and culminated in the revelation of the alkyl-melamine baking enamels. 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 thermoplastic. The former do not normally require primers, though nowadays primerless thermoplastics have also been developed; they have greater chemical and solvent resistance and improved flexibility-hardness relationships; and they are easy to handle. The usual thermosets—the epoxies and now polyesters and polyacrylates 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 initially. However, for that matter, the edge coverage properties of the thermosets are poorer. The thermoplasts having high molecular weights do not flow off the edges and hence ensure a better coverage. The most important way of improving thermoplasts is the use of a blend of both thermoset and thermoplastic 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 recently, and hopes were expressed that thermosets would outstrip their rival shortly. However, the emergence of sprayable primerless thermoplasts makes this forecast doubtful. The figures 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 figures (epoxies, 33-41%; vinyls (PVC and PVA), 17-33%; polyesters, 8-10%; nylon, 3-10%; and others like polyethylene and cellulosics, 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 acrylics have reached the stage of commercial development. Cellulosics, polyesters and polypropylene have of late been prepared as sprayable thermoplastic powders. Polyurethane is also now available for powder coating.

Methods of Application

The two chief methods of application are: (i) fluidized bed dipping and (ii) electrostatic methods. 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, causing 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 bed and (ii) electrostatic spray. 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 deposit. But the fluidized bed method is somewhat more difficult to control. The spray method also has the drawback of overspray and without an attached reclaimation 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 desired. 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 surfaces. Kessler attributes the growth of powder coatings to the electrostatic spray techniques only. It is well...
adapted for the interior coating of pipes and tubes. In fluidized bed techniques, mostly the thermoplastic resins 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 only. The fluidized bed dip method and the spray method are, therefore, ideal for protective and decorative coatings respectively. Films obtained by the spray powder coating method come close to those obtained from solvent-based finishes which have a thickness of 1-5 mils. Powders of cellulose-acetate-butyrates for fluidized bed and electrostatic spray methods are 50 and 150 mesh respectively. In terms of particle size, 52-340 μ is recommended for the fluidized bed technique and 75μ for the electrostatic technique.

Characteristics of Powders

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 obtain and this is the reason why films resulting from powders are usually thinner than those of solvent-based paints. In ultrathin (below 1μ) and superfine (1-10μ) 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. Harris considers particles in the size range 10-100μ as 'granular' and recommends granular particles of 50-300μ 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 x 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, sign, bus seats, vacuum cleaners and sewing machines 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. The construction industry and appliances are likely to be major consumers of powder coatings. The possible aircraft uses 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 recently 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 consolidation. 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.

Merits of Powder Coatings

Many of the solvents are toxic and their presence in air is inimical to eyes, vegetation and buildings. The contribution of surface coatings to the general air pollution is an important point. According to a 1961 survey carried out in Holland, it was 0.1% of the total pollution, whereas in California it is stated to be as high as 10%. 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 retention.

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 automate. 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 result. In fact, powder coated materials have been shown to withstand rough 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 favourable.

As the costs 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 required. Cleaning is simply by sweeping, vacuuming or even shaking, and this
is definitely easier than cleaning the equipment using solvent-borne materials. Also, there is no need for demineralized water.

**Demerits of Powder Coatings**

The economics of spraying depends on the efficiency of reclaimation of the split-over powder. In automatic sprays, this is 90%, in the case of dry products and 70% in the case of wet products. Straight filtering, nitrogen bag and cyclone filters are two standard methods of reclaimation. Of these, cyclones with follow-up bag housings are more popular. But cyclones have the tendency to retain only coarse, larger and heavier particles, rendering the reconstitutions of the powder with the original characteristics difficult.

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

Change of colour/powder or batch is a challenge to reclaimation. 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 purpose. Resins suitable for powder coatings and in desired colours (especially metallic ones) 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. Large three-dimensional objects, the electrostatic method is better.

Glass is dependent upon the smoothness of the first coat and the overall drying hard about 30 minutes after drying in air. Physical handling is hazardous to grinding. Production times have improved as in the film. The powder is not expensive. It is a primary surface agent and is also a depolarizer. It is applied to the coating texture and has a durable result on the glass. The faster curing increases the line speed; therefore, the recapitulation of colour curing, while enhancing line speed and sharp-edge coverage, invariably improves the gloss. By proper choice of hardeners, a compromise can be found 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 metal interface, as solvent-based finishes do.

**Future Trends**

Some of the future trends according to Harris 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 line 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 harder systems; and (v) development of a powder that can be coated in 1-4 mil thickness with good weatherability. In conclusion, it may be stated that the huge volume of activity in this field as evidenced by the large number of papers and patents 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 powderers 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.

**References**

2. **Barnes, J.T., J. Oil Colour Chem. 46, 54 (1971).**
3. **American Pig. Resin Technol., 1(11) (1972).**
4. **Chinnamuthu, I.T, J. Oil Colour Chem. Ass., 56 (1973), 144.**
6. **Gardner, I.A. and Dugger, R., Pig. Resin Technol., 1(10) (1972).**
7. **Krak, H. and Saal, A., Surf. Coat., 6(2) (1972), 43.**
10. **Tate, P.S., "Pigments, Wt. & Inks, P. Pigment, **
11. **of the Vinyl Acetate and polyvinyl Chloride;**
12. **American Chemical Society, 112.**
13. **1972, 722.**
15. **Parker, J., Pig. Resin Technol., 2(9) (1972), 14.**
17. **Mann, A., Paint Varnish Prod., 60(9) (1970), 25.**
18. **Harris, T.E., J. Oil Colour Chem. Ass., 56 (1973), 583.**
19. **Ramsay, M.W., Powder coatings and fluidized-bed techniques (Noyes Data Corporation, New Jersey), 1973.**
22. **Safety in Electrostatic Spraying of Powder Coatings (Paint- OEM's Association of Great Britain, UK), 1973.**
23. **Chidlow, E.N. and Holappa, H.S., Pig. Resin Technol., 1(10) (1972), 12.**
24. **Katten, J., Ind. Plant, 46(7) (1909), 58.**
25. **Peter, E.E., Proceedings, First North American Conference on powder coatings, (Canadian Paint Finishing, Toronto), 1971, 37.**
30. IAMER, M. C., Pig. Resin Technol., 1(10) (1972), 19.
33. DAY, W., J. Oil Colour Chem. Ass., 56 (1973), 149.