COATING PROCESSES, SPRAY

1. Introduction

A coating may be applied to articles, ie, workpieces, by spraying. This application method is especially attractive when the articles have been previously assembled and have irregularly shaped and curved surfaces. The material applied is frequently a paint (qv), ie, a combination of resin, solvent, diluent, additives, and pigment. The material can also be a hot thermoplastic, an oil, or a polymer dissolved in a solvent. Many types of spray equipment are available. Methods can be used in combinations, and most of the techniques can be used for simple one-applicator manual systems or in highly complex computer-controlled automatic systems having hundreds of applicators. In an automatic installation, the applicators can be mounted on fixed stands, reciprocating or rotating machines, or even robots (Fig. 1).

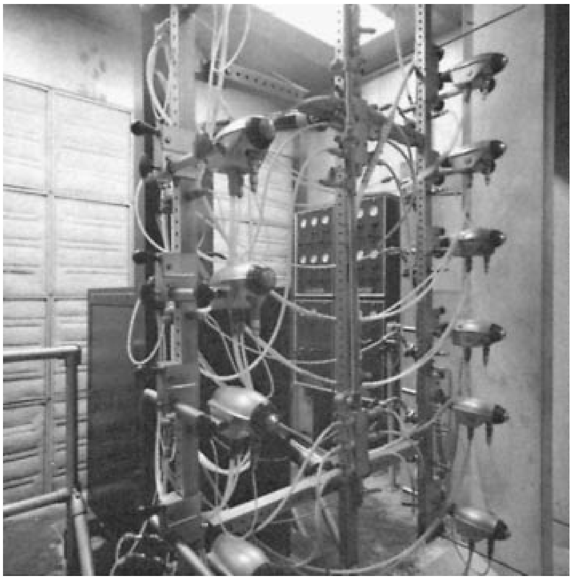

Fig. 1. An automatic spray-coating system, where air-automized electrostatic spray guns are mounted on reciprocators.

2. Atomization

2.1. Airless Atomization. In airless- or pressure-atomizing systems, the coating is atomized by forcing the coating (or the liquid) through a small-diameter nozzle under high pressure. The fluid pressure is typically between 5 and 35 MPa (700–5000 psi); fluid flow rates are between 150–1500 cm^3/min. In most commercial applications, a pump designed for the type of material sprayed is used to develop the high pressure. The pump can be mechanically, electrically, pneumatically, or hydraulically driven and the nozzle apertures have diameters ranging from 0.2 to 2.0 mm. The more viscous the fluid and the higher the desired liquid-flow rate, the larger the nozzle. As the fluid is forced through the nozzle, it accelerates to a high velocity and leaves the nozzle in a thin sheet or jet of liquid in the relatively motionless ambient air, producing a shear force between the fluid and air. The fluid is atomized by turbulent or aerodynamic disintegration, depending on the specific conditions (Fig. 2). The most common nozzles produce a long, narrow fan-shaped pattern of various sizes; others produce a solid or hollow cone. The pattern of a fan nozzle can split and form “fingers” if the pressure is not sufficient. Because the coating material is often abrasive, the nozzle is typically made from tungsten carbide (see CARBIDES).

Airless atomization generally produces a medium-to-coarse particle size. Using a given nozzle, the higher the fluid pressure, the finer the atomization. Airless atomization can be used to atomize a large amount of material, or can atomize at high flow rates that can be rapidly deposited on the workpiece with minimal overspray or misting and excellent penetration into recessed areas.

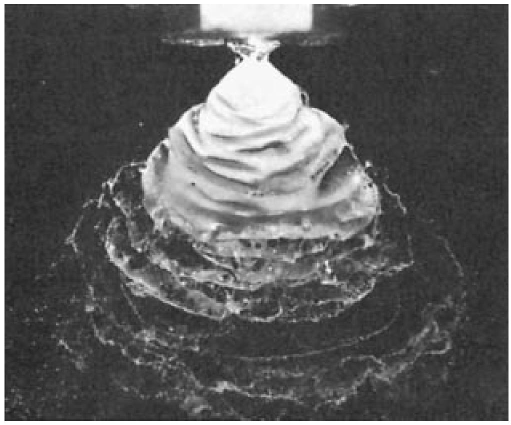

Fig. 2. Airless atomization process.

The flow rate is controlled by the nozzle size and the fluid pressure. The minimum nozzle size is determined by the size required to prevent plugging under operating conditions; minimum application pressure is determined by the required degree of atomization and the elimination of fingers.

A variation of airless atomization is called air-assisted airless. A small amount of compressed air at 35–170 kPa (5–25 psi) is introduced adjacent to the airless nozzle and impinges upon the thin sheet of fluid as it exits from the nozzle. This air aggravates the turbulence in the fluid and results in improved atomization at lower fluid pressures. Often, material that cannot be properly atomized using straight airless atomization can be using the air-assisted airless method. In some cases, the introduction of the air allows some control of the fan size.

2.2. Supercritical Atomization. Atomization can be obtained by mixing a supercritical fluid (SCF) with the material to be atomized. This process reduces volatile organic compound (VOC) emissions as the SCF acts as a solvent and replaces some of the hydrocarbon solvents in the material (see SUPERCRITICAL FLUIDS).

The material sprayed is generally a very high solids or viscous material that is thinned with the SCF to a spray viscosity in a special mixing/metering system. This mixture is then sprayed in an airless-type spray gun specifically designed for the process. In addition to the pressure or airless-type atomization, there is secondary atomization that results when the SCF dissolved in the spray material changes to a gas and rapidly expands (Fig. 3). Thus atomization quality is excellent, and materials that cannot be atomized using other methods can be used.

An aerosol container can be considered a special application of airless atomization (see AEROSOLS). The pressure is usually supplied by a liquefied gas in the container at its equilibrium pressure. The material being sprayed has a very low viscosity to provide easy material flow through the feed tube and to permit fine atomization.

2.3. Air Atomization. In an air atomizer, an external source of compressed air, usually supplied at pressures of 70–700 kPa (10–100 psi), is used

Fig. 3. Supercritical fluid atomization process.

to atomize the liquid. Air atomization is perhaps the most versatile of all the atomization methods. It is used with liquids of low to medium viscosity, and flow rates of 50–1000 cm^3/min are common. Medium-to-fine particle sizes are produced, and the resulting surface finish is very good. It is sometimes difficult to penetrate small recessed areas, however, because the atomization air forms a barrier in the recess that the coating particles must then penetrate. When higher air pressures are used, air atomization produces considerable misting and overspray, which can be a disadvantage under some conditions. Air-atomizing devices can be of internal- or external-mix design.

The most common type of air atomizer is an external-mix where the coating material and atomization air are mixed in the space in front of the nozzle and air cap. An annulus of air generally surrounds the fluid as it leaves the tip, and the shear stress between the fluid and the air causes the initial atomization. In addition to the annulus, numerous (in some cases, as many as 10) air holes are placed in the air cap to direct air jets that continue the atomization process, assist in keeping the cap clean, and help shape the spray. Air jets coming from holes located in two diametrically opposed “horns” or ears produce a fan-shaped pattern that is oriented 90° from the horns. Where a fan pattern is not required, special nozzles expel the coating from a circular annulus about 0.6 mm thick surrounded by an air annulus. A swirl imparted to the atomization air in the annulus results in a very efficient atomization process and a spray having low momentum and misting. This is especially useful when coating long, narrow objects or when the atomizers are reciprocated or rotated to blend the patterns from several atomizers. It is difficult to coat a flat surface manually using this type of spray pattern.

In an internal-mix nozzle, the atomization air is mixed with the coating material before being forced through a nozzle or tip. As the mixture of air and coating material passes through the nozzle, its pressure is significantly reduced, and the resulting expansion produces the atomization of the coating material. This is a very efficient method of atomization, but usually coating material builds up around the fluid tip where the atomization occurs. This material is then torn away without being properly atomized, producing slugs that may be deposited on the workpiece and blemish the finish. It is therefore necessary to clean the tip of an internal-mix air atomizer frequently.

A special case of air atomization is high volume low pressure (hvlp) spray. In this case the air pressure at the spray gun is less than 70 kPa (10 psig) and there are relatively large (up to 0.32 cm) holes in the air cap to easily pass the low pressure air. This type of atomizer produces a soft or slow moving spray and is generally considered to be rather efficient in depositing the material on the workpiece. However, the use of low pressure air for atomization usually limits the viscosity and/or flow rate of the material that can be atomized.

The fluid delivery in an air-spray system can be pressure or suction fed. In a pressure-fed system, the fluid is brought to the atomizer under positive pressure generated with an external pump, a gas pressure over the coating material in a tank, or an elevation head. In a suction system, the annular flow of air around the fluid tip generates sufficient vacuum to aspirate the coating material from a container through a fluid tube and into the air stream. In this case, the paint supply is normally located in a small cup attached to the spray device to keep the elevation differential and frictional pressure drop in the fluid-supply tube small.

Most industrial production systems use a pressure-feed system, whereas many touch-up and recoating operations use suction feed. In a pressure-feed system, the fluid-flow rate and the atomization air are controlled independently. This permits the fluid-flow rate to be set to the desired value within a very large range. The pressure of the automization air is then matched with the fluid-flow rate to give the desired fineness of atomization. In a suction-feed system, the coating flow rate is determined by the flow of the atomization air and the size of the fluid orifice. Generally, it is not possible to suction feed more material than can be atomized by the quantity of air being used. A suction-feed system works best with low viscosity fluids, as the pressure differential available to transport the fluid is small, and higher viscosity liquids generally do not have sufficient flow rate for practical applications.

2.4. Electrostatic Atomization. The atomization of the coating material by electrostatic forces occurs when an electrical charge is placed on a filament or thin sheet of coating, and the mutual repulsion of the charges tears the coating material apart. For this process to produce acceptable atomization, the physical properties of the coating material must be within a relatively narrow range. The material is charged by an external source of high voltage, either prior to or as it is forced to flow over a knife edge, through a thin slot, or orifice, or it is discharged from the edge of a slowly rotating disk or bell (cup). The thin sheet or small diameter stringers or cusps of coating material are torn apart by the mutual repulsion of the charges on the material.

When a disk or bell is used, the coating material is fed near the center, and the rotation, generally 900–3600 rpm, provides a means of distributing the coating material to the edge of the device. At the edge, fluid surface tension or mechanical features of the rotating surface become the controlling factor, and the coating material comes off the surface in cusps. At higher rotation speeds, mechanical forces become significant and the stringers can break off at their base, resulting in larger particles being formed. Electrostatic atomization is limited to about 4 cm^3/min per centimeter of discharge length; voltages of 100–150 kV are used. This can be a very efficient coating method, but because of the required combination of low surface tension, low viscosity, and proper balance of electrical characteristics, this method of atomization has not been very successful for high solids or waterborne coatings (see COATINGS). Penetration into recessed areas is generally fair to poor, and excessive buildup of material on edges of the workpiece is possible.

2.5. Rotary Atomization. In rotary atomization, a bell (cup) or disk rotates at a speed of 10,000–40,000 rpm. In contrast to electrostatic atomization, mechanical forces dominate. The coating material is introduced near the center of the rotating device, and centrifugal force distributes it to the edge, where the material has an angular velocity close to that of the rotating member. As the coating material leaves the surface, its main velocity component is tangential, and it is spun off in the form of a thin sheet or small cusps as illustrated in Figure 4. The material is then atomized by turbulent or aerodynamic disintegration, depending on exact conditions. The diameter of a typical bell is 4–10 cm, whereas that of a disk is typically 10–25 cm. When a bell is used, the part to be coated is transported across the open face of the bell. A disk is generally used in an

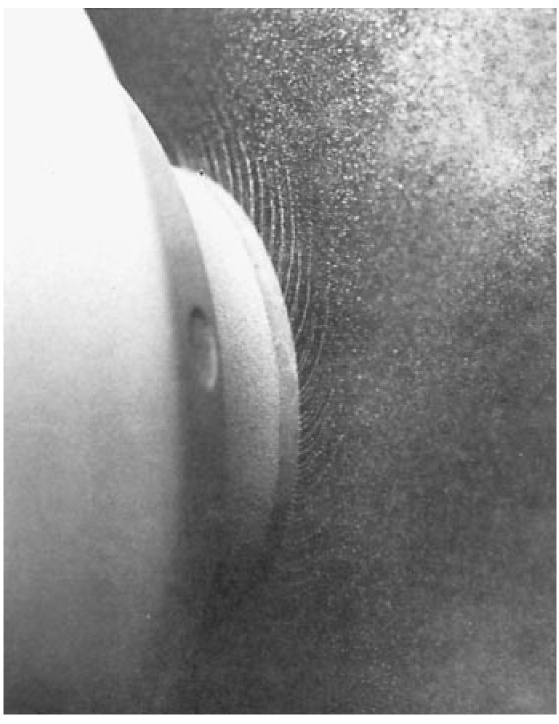

Fig. 4. Rotary atomization process.

omega-shaped loop with the centerline of the disk on the centerline of the loop. The disk has a 360° spray pattern and is reciprocated up and down to cover the length of the part.

Rotary atomization produces the most uniform atomization of any of the aforementioned techniques, and produces the smallest maximum particle size. It is almost always used with electrostatics and at lower rotational speeds the electrostatics assist the atomization. At higher rotational speeds the atomization is principally mechanical in nature and does not depend on the electrical properties of the coating material. If the viscosity of a coating material is sufficiently low that it can be delivered to a rotary atomizer, the material can generally be atomized. The prime mover is usually an air-driven turbine and, provided that the turbine has the required power to accelerate the material to the angular velocity, liquid-flow rates of up to 1000 cm^3/min can be atomized using an 8-cm diameter bell.

Rotary atomization produces an excellent surface finish. The spray has low velocity, which allows the electrostatic forces attracting the paint particles to the ground workpiece to dominate, and results in transfer efficiencies of 85–99%. The pattern is very large and partially controlled and directed by shaping air jets. The spray when using a metallic cup has relatively poor penetration into recessed areas. Excessive material deposited on the edges of the workpiece can also be a problem.

Recent developments in rotary atomization include the use of semiconductive composites (qv) for the rotary cup permitting the construction of a unit that does not produce an ignition spark when brought close to a grounded workpiece yet has the transfer efficiencies associated with a rotary atomizer. In addition, the use of the semiconductive material softens the electrostatic field and results in less edge buildup and better penetration into recess areas. Other systems use electronic means to effectively prevent arcing to grounded surfaces.

3. Electrostatic Spraying

Use of electrostatic spraying or electrostatic deposition increases the efficiency of material transfer to the workpiece (see COATING PROCESSES, POWDER TECHNOLOGY). The cost of solvents and coating materials and the emphasis on reducing emissions to the atmosphere have both increased dramatically since the late 1970s. These factors have effected an emphasis on increased transfer efficiency, ie, the fraction of the material removed from the coating bucket that is placed on the workpiece. The transfer efficiency is affected by the painting technique, workpiece geometry, the coating material, how the workpiece is presented to the atomizer, the ambient air movement, and other variables.

Electrostatic forces can be very effective in increasing the transfer efficiency. An electrical charge, usually negative, is placed on the coating material before atomization or as the coating particles are being formed. This is accomplished either by direct charging, where the coating material comes in contact with a conductor at high voltage, or by an indirect method, where the air in the vicinity of the coating particles is ionized and these ions then attach themselves to the coating particles. An external voltage source of 60–125 kV is normally used. A voltage gradient is established between the vicinity of the atomizer and the grounded workpiece by using the charged coating particles, charged metal atomizer, or an electrode near the atomizer as a local source of a high voltage field. An electrostatic force is exerted on each coating particle equal to the product of the charge it carries and the field gradient. The trajectory of the particle is determined by all the forces exerted on the particle. These forces include momentum, drag, gravity, and electrostatics. The field lines influencing the coating particles are very similar in arrangement to the alignment of iron particles when placed between two magnets. Using this method, coating particles that would normally pass alongside the workpiece are attracted to it, and it is possible to coat part or all of the back side of the workpiece.

Electrostatic spray atomizers are constructed from metal or nonconductive materials. A metal atomizer has sufficient electrical capacitance that when it is approached rapidly by a grounded object, eg, workpiece, an electrical arc may occur that can have sufficient energy to ignite certain solvent-air mixtures. A metal atomizer offers maximum ruggedness and efficiency but may present a fire hazard if not electronically protected. Thus this type of system often employs an electronic feedback system to reduce voltage and prevent arcing under these conditions. Most nonconductive atomizers are of a nonincendiary design; the rate of energy discharge has been specifically limited in such a way not to cause ignition. However, this type of atomizer is generally not as rugged as a metal atomizer, and in operation, the working voltages decrease, resulting in somewhat lower transfer efficiency.

All of the atomization techniques that produce a spray can be used with electrostatic spraying. Electrostatic atomization by definition uses electrostatic deposition. Furthermore, in rotary atomization the momentum toward the workpiece is relatively low and the transfer efficiency very poor if it is used without electrostatic deposition. Air and airless sprays also benefit from electrostatics in transfer efficiency. One problem for electrostatic spraying is that penetration into recessed areas is more difficult because the coating particles are attracted to the edges of the workpiece. The edges are closer to the high voltage source and therefore concentrate the field gradients. This problem can be overcome by reducing the voltage level or by using atomizers having high particle momentum, such as air or airless atomizers.

4. Economic Aspects

Spray equipment is marketed in a variety of ways in the United States. Several large manufacturers have broad product lines and sell equipment both directly to the user and through distributors. These companies can also provide custom engineered automatic systems for specific application. The largest U.S. manufacturers include Binks, Graco, ITW (DeVilbiss and Ransburg), and Nordson. There is also a multitude of smaller companies that provide a limited product line. Automatic spray systems can also be purchased through system houses that engineer an entire system, which might include the pretreatment system, ovens, and conveyor line.

Both individual components and small prepackaged systems are usually available from the many general distributors as are manual systems. Some manual systems are purchased in conjunction with automatic systems. Some of the larger distributors also custom design small automatic systems using standard components.

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