

Osswald · Baur · Brinkmann
Oberbach · Schmachtenberg

International Plastics Handbook

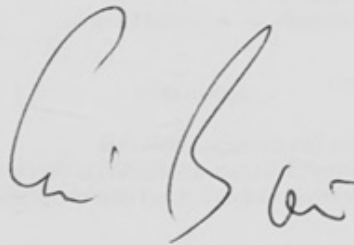
The Resource for Plastics Engineers

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A handwritten signature in black ink, appearing to read 'C. Baur', is centered on the page. The signature is fluid and cursive, with the first letter 'C' being large and prominent.

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The Authors:

Prof. Dr. Tim A. Osswald, Department of Mechanical Engineering University of Wisconsin-Madison,
Madison, WI, USA
Dr. Erwin Baur, M-Base GmbH, Aachen, Germany
Sigrid Brinkmann, Brinkmann Kunststofftechnologie und Redaktion Bad Aibling, Germany
Karl Oberbach, Leuchter Gemark 3, 51467 Bergisch Gladbach, Germany
Prof. Dr.-Ing. Ernst Schmachtenberg, Institute of Polymer Technology, University of Erlangen-Nuremberg,
Germany

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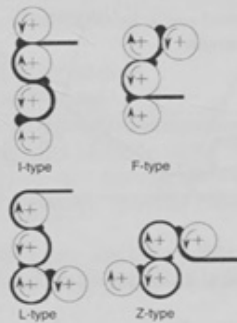


Figure 4.122: Calendar arrangements.

4.9 COATING

In coating a liquid film is continuously deposited on a moving, flexible or rigid substrate. Coating is done on metal, paper, photographic films, audio and video tapes, and adhesive tapes. Typical coating processes include wire coating, dip coating, knife coating, roll coating, slide coating, and curtain coating. In wire coating, a wire is continuously coated with a polymer melt by pulling the wire through an extrusion die. The polymer resin is deposited onto the wire using the drag flow generated by the moving wire and sometimes a pressure flow generated by the back pressure of the extruder. The process is schematically depicted in Fig. 4.123⁸. The second normal stress differences, generated by the high shear deformation in the die, help keep the wire centered in the annulus. Dip coating is the simplest and oldest coating operation. Here, a substrate is continuously dipped into a fluid and withdrawn with one or both sides coated with the fluid. Dip coating can also be used to coat individual objects that are dipped and withdrawn from the fluid. The fluid viscosity and density and the speed and angle of the surface determine the coating thickness. Knife coating, depicted in Fig. 4.124, consists of metering the coating material onto the substrate from a pool of material, using a fixed rigid or flexible knife. The knife can be normal to the substrate or angled and the bottom edge can be flat or tapered. The thickness of the coating is nearly half the gap between the knife edge and the moving substrate or web. A major advantage of a knife edge coating system is its simplicity and relatively low maintenance. Roll coating consists of passing a substrate and the coating

⁸Other wire coating operations extrude a tubular sleeve which adheres to the wire via stretching and vacuum. This is called tube coating.

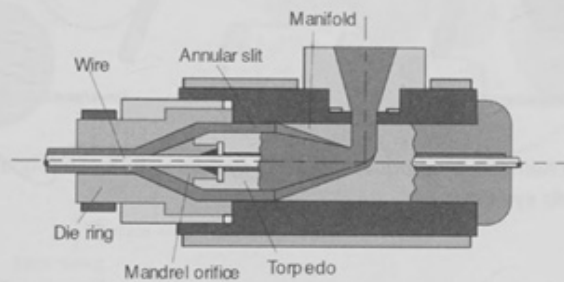


Figure 4.123: Schematic of the wire coating process.

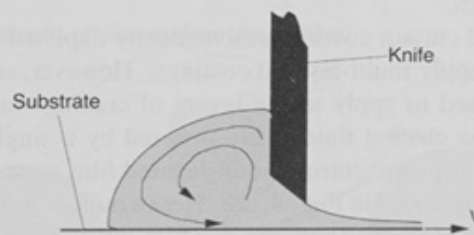


Figure 4.124: Schematic of the knife coating process.

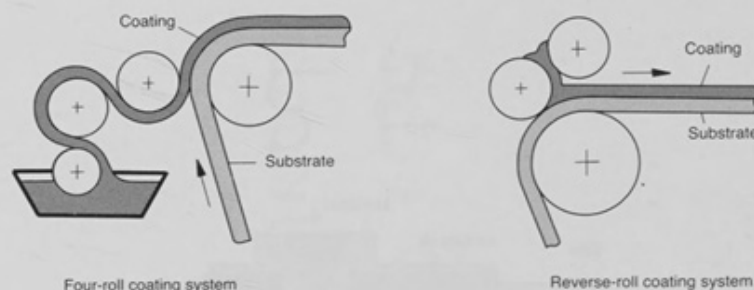


Figure 4.125: Schematic of a four-roll coating system with forward-coating rolls and a reverse-coating rolls system.

simultaneously through the nip region between two rollers such as shown in Fig. 4.125 for a four-roll with forward-roll system and reverse-roll coating system. As can be seen, the physics governing this process is similar to calendaring, except that the fluid adheres to both the substrate and the opposing roll. The coating material is a low viscosity fluid, such as a polymer solution or paint and is picked up from a bath by the lower roll and applied to one side of the substrate. The thickness of the coating can be as low as a few μm and is controlled by the viscosity of the coating liquid and the nip dimension. As shown, roll coating systems can be configured as either forward-roll coating for co-rotating rolls or reverse-roll coating for counter-rotating rolls. The reverse roll coating process delivers the most accurate coating thicknesses.

In melt roll coating systems the polymer is delivered into the nip region in powder form, granules, or sometimes pre-plasticized from an extruder, such as depicted in Fig. 4.126.

Slide coating and curtain coating, schematically depicted in Fig. 4.127, are commonly used to apply multi-layered coatings. However, curtain coating has also been widely used to apply single layers of coatings to cardboard sheet. In both methods, the coating fluid is pre-metered by a single screw extruder. Another technique of manufacturing multi-layered film systems is the *hot melt* laminating process presented in Fig. 4.128. Here a molten polymer, delivered by an extrusion die, is sandwiched between two film substrates, cooled and spooled onto a roll.

It is also common to laminate finished films into multi-layered systems by heating the polymer films and pressing the laminate between roll systems as schematically depicted in Fig. 4.129.

Another common coating technique is to metallize films by evaporating aluminum onto a heated roll inside a vacuum chamber, such as shown in Fig. 4.130. For a successful process the required vacuum must be 10^{-4} mbar. This semi-

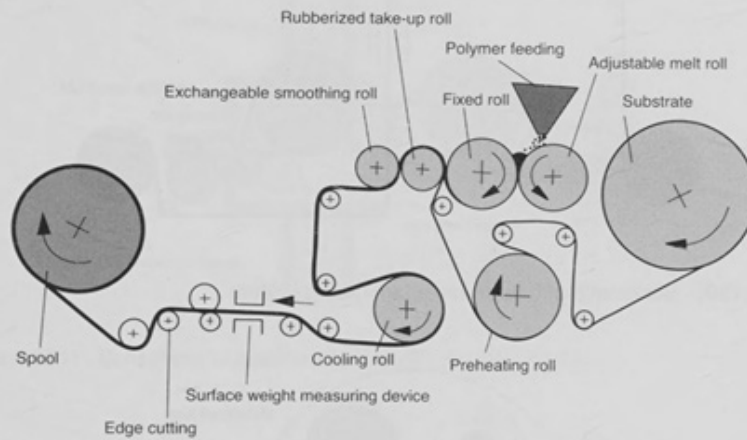


Figure 4.126: Schematic of a melt roll coating system.

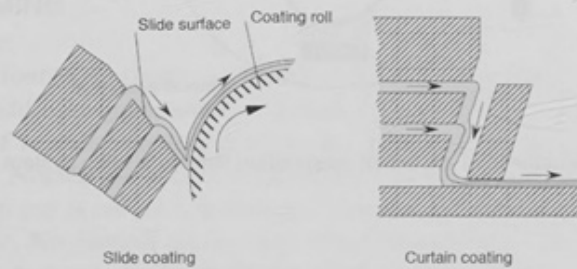


Figure 4.127: Schematic of slide and curtain coating.

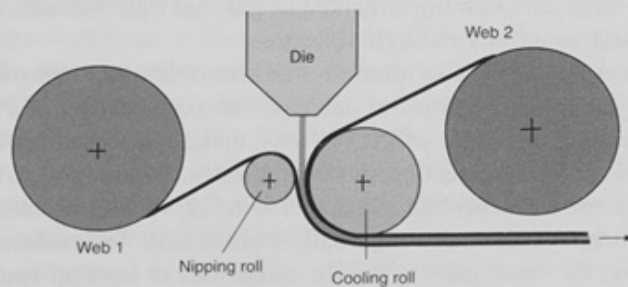


Figure 4.128: Schematic of a hot melt three-layer laminating system.

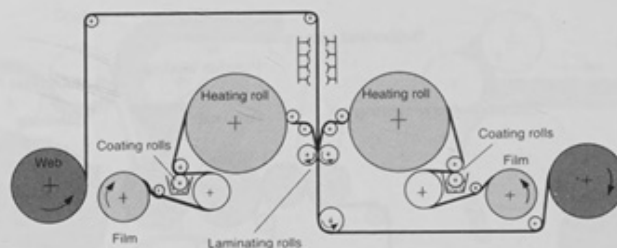


Figure 4.129: Schematic of a three-layer laminating system.

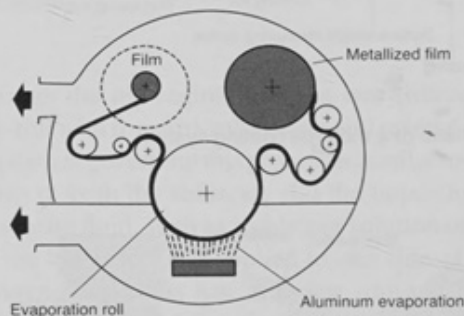


Figure 4.130: Schematic of a thermal evaporation film metallizing system.

continuous process is mostly used to metallize plastic film with aluminum, however, more recently it has been used to coat SiO_x onto films. The aluminum layers are between 0.03 and $0.04 \mu\text{m}$ thick, and the film thicknesses can be as low as $9 \mu\text{m}$, for PET, and $15 \mu\text{m}$, for PP and PC, with widths between 0.3 and 2.4 m. Such films are often implemented as gas and light barriers, decoration, conductive condensor films and light reflectors.

Finally, *plasma coating*, also referred to as *chemical vapor deposition* (CVD) is a widely used coating process to decrease the permeability of PET bottles, increase the scratch resistance of PC surfaces, make surfaces either hydrophilic or hydrophobic, add UV protection, modify the index of refraction, to name a few. During plasma coating, schematically depicted in Fig. 4.131, a monomer is added to a low pressure plasma (totally or partially ionized gas). The collisions between the plasma and the monomers cause the molecules to heat up spontaneously, leading to the opening of chemical bonds, which normally would only occur at high temperatures. Having chosen the appropriate monomer this will trigger a reaction that will lead to a thin coating on the substrate. For example, a 0.1

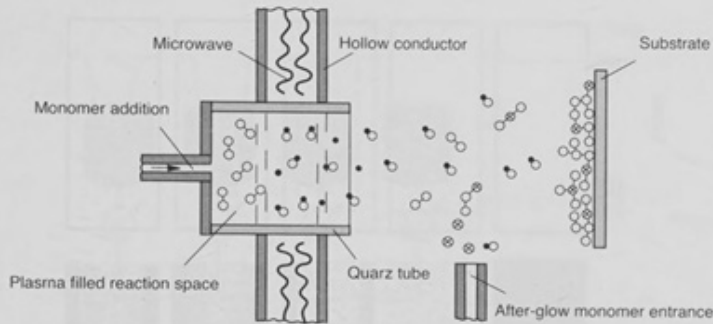


Figure 4.131: Schematic of plasma polymerization coating process.

to 0.8 μm thick layer of Si-O_2 can be deposited on PC, to make light lenses scratch-resistant for automotive applications.

4.10 FOAMING

In foam or a foamed polymer, a cellular or porous structure has been generated through the addition and reaction of physical or chemical blowing agents. The basic steps of foaming are cell nucleation, expansion or cell growth, and cell stabilization. Nucleation occurs when, at a given temperature and pressure, the solubility of a gas is reduced, leading to saturation, expelling the excess gas to form a bubble. Nucleating agents, such as powdered metal oxides, are used for initial bubble formation. The bubbles reach an equilibrium shape when their inside pressure balances their surface tension and surrounding pressures. The cells formed can be completely enclosed (closed cell) or can be interconnected (open cell). A physical foaming process is one where a gas such as nitrogen or carbon dioxide is introduced into the polymer melt. Physical foaming also occurs after heating a melt that contains a low boiling point fluid, causing it to vaporize. For example, the heat-induced volatilization of low-boiling-point liquids, such as pentane and heptane, is used to produce polystyrene foams. Also, foaming occurs during volatilization from the exothermic reaction of gases produced during polymerization such as the production of carbon dioxide during the reaction of isocyanate with water. Physical blowing agents are added to the plasticating zone of the extruder or molding machine. The most widely used physical blowing agent is nitrogen. Liquid blowing agents are often added to the polymer in the plasticating unit or the die. Chemical blowing agents are usually powders introduced in the hopper of the molding machine or extruder. Chemical foaming occurs when the blowing agent thermally decomposes, releasing large amounts