ADHESION

Good adhesion is usually the key requirement in extrusion coating. A coating which does not adhere to the substrate or which can be easily peeled off is worthless.

THE NATURE OF ADHESION

The nature of the adhesion between polyethylene and the substrate is either physical (mechanical) or chemical, depending on the type of substrate involved (i.e. porous or non-porous).

Polyethylene coatings can form a mechanical bond with porous substrates (such as kraft paper or cloth) as the polymer is able to flow into the pores of the substrate. The two surfaces physically lock together and can be difficult to separate. Most smooth, non-porous substrates such as metal foils or plastic films have less physical means of adhering to the coating. They tend to resist adhesion, and the substrate and coating must be chemically bonded.

The adhesion between the polyethylene and the substrate is measured by the peel strength, which is the force required to peel a strip of the laminate apart when tested in a tensile machine.

Oxidation of the Polyethylene

To obtain a chemical bond between the coating and non-porous substrates, oxidation of the polyethylene surface is necessary. Such oxidation requires a high melt temperature and an adequate draw-down distance (or air gap) between the die and the chill roll nip. The air gap is needed simply to give adequate time for oxidation to occur. However, an excessive air gap will allow cooling of the melt, which will impair adhesion. Oxidation also plays a minor role in coating porous substrates.

The recommended time in the air gap (TIAG) for polyethylene is between approximately 80-120 ms. It may be less for some porous substrates, or where very good adhesion is not required. TIAG can be calculated using the following equation.

$$\text{Time in the Air Gap (TIAG)} = \frac{60 \times \text{air gap (mm)}}{\text{line speed (m/min)}}$$

The air gap can be adjusted by raising or lowering the extruder or the nip roll assembly.

Any factor which reduces the amount of oxidation of the hot polyethylene web reduces its chemical adhesion to the substrate. These factors include: low melt temperature, small air gap, high coating speed and low coating weights.

Fourier Transform Infrared (FTIR) examination of polyethylene materials has been shown to be a reliable technique to assess the degree of oxidation of polyethylene. The amount of oxidation can be measured by the Carbonyl Index, which is the ratio of the absorbance of a selected carbonyl peak (1,700-1,750 cm^{-1}) to that of a reference peak of the polymer.

Preheating the Substrate

The preheating of porous materials, like kraft paper, cloth or woven fabrics, helps adhesion. The surface becomes more receptive to the molten polymer by being dried and warmed. Preheating the surface of non-porous substrates such as metal foil or glossy paper will also help remove moisture as well as lubricants, thus promoting adhesion.

However, preheating affects only the substrate surface; it does not really penetrate into the web because of the very short heating duration. Wet, porous substrates are rarely dried by preheating. Such substrates should be oven-dried before being used in the extrusion coater.

Preheating can be achieved by passing the substrate over a heated steel drum (at approximately 175 to 190°C). Gas flames or radiant heaters are also used. Flame treating with an oxidising flame will assist adhesion by oxidising the substrate surface and creating adhesion-promoting groups.

Factors Affecting Adhesion

The adhesion of the polyethylene coating to the substrate depends upon a number of factors, including:

- **The nature of the substrate.** This has been discussed earlier in relation to porous and non-porous substrates.
- **Melt temperature.** Adhesion improves as the melt temperature is increased, as shown in Figure 1.
- **Chill roll temperature.** Too low a chill roll temperature will impair adhesion. Increasing the temperature of the chill roll will help overcome quick cooling.
- **Polymer flow properties (MFI).** Higher MFI polyethylenes, with their lower viscosity, adhere better to porous substrates than lower MFI grades (see Figure 2).
- **Nip roll pressure.** Low nip roll pressure will cause poor adhesion, but increasing the pressure above a critical level gives no extra benefit (see Figure 3).
- **The air gap.** A larger air gap allows more oxidation of the surface, thus promoting adhesion, as discussed earlier (see Figure 4).
- **Coating speed and coating weight.** Low coating speed and high coating weight tend to promote adhesion because more time is available for oxidation to occur (see Figure 5). As thinner coatings are extruded, they cool more in the air gap and adhesion may become poorer.

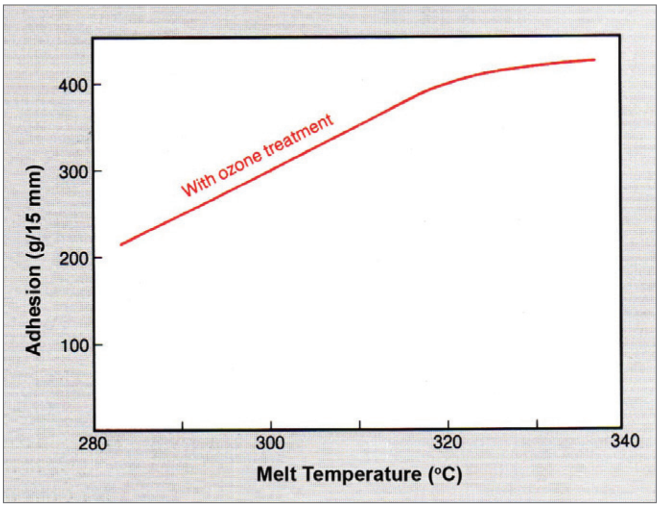

Figure 1: Effect of Melt Temperature and Ozone Treatment on Adhesion of Extrusion-Coated LDPE to Aluminium Foil

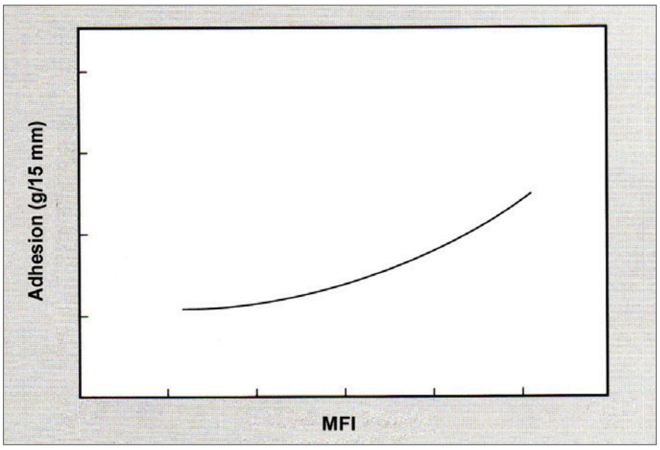

Figure 2: Effect of MFI on Adhesion of Extrusion-Coated LDPE to Porous Substrates

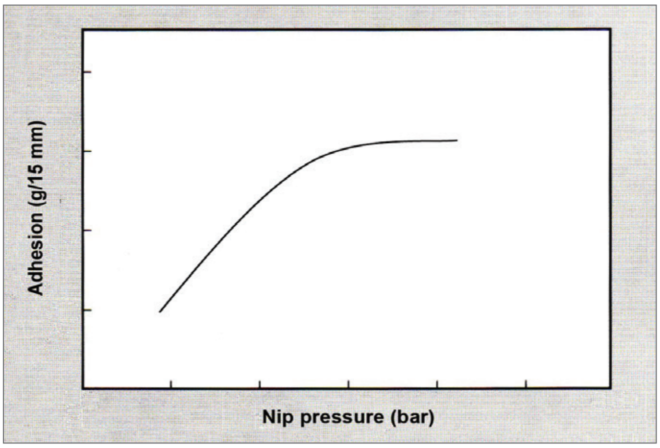

Figure 3: Effect of Nip Pressure on Adhesion of Extrusion-Coated LDPE to Porous and Non-Porous Substrates

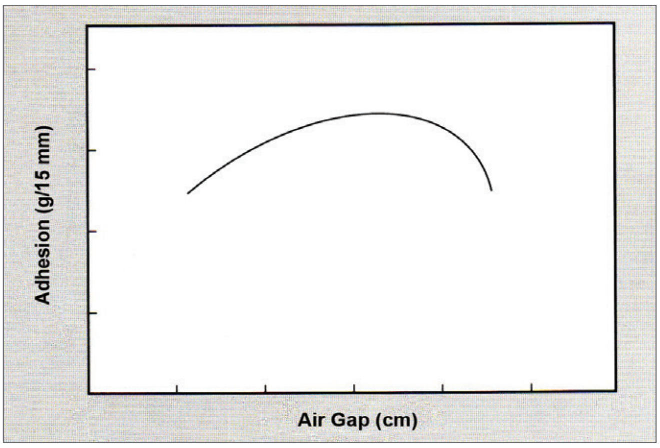

Figure 4: Effect of Air Gap on Adhesion of Extrusion-Coated LDPE to Non-Porous Substrates

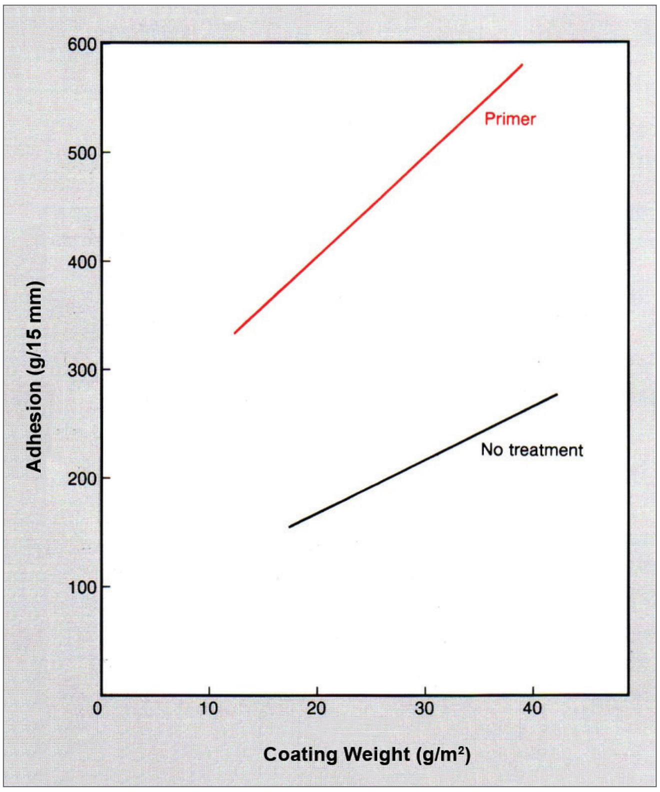

Figure 5: Typical Effect of Coating Weight on Adhesion of Extrusion-Coated LDPE to Aluminium Foil (60 m/min, 307ºC)

Coating experiments carried out with kraft paper have shown that the lower the coating weight, the higher the melt temperature required to obtain good adhesion; conversely, the higher the coating weight, the lower the required melt temperature.

Use of Primers

It is difficult to obtain good adhesion between polyethylene and a number of common substrates without first treating or priming the substrate surface. Primers are chemicals which when applied as a discrete layer to the substrate surface provide a chemical affinity between the extruded web and the substrate and hence lead to better adhesion. Substrates which often require priming before coating are aluminium foil, polyester and oriented and cast polypropylene films. Many papers and paper boards are primed to achieve maximum line speeds at low coating weights.

In-line priming is the most economical method, as this avoids additional unwind and rewind steps. Figure 6 shows a schematic drawing of an in-line priming station. Effective priming may also reduce the required melt temperature.

Primers can be solvent- or water-based and either curing (reactive) or non-curing systems. There is no universal primer; primer selection is specific to a particular application and the final use of the laminated material.

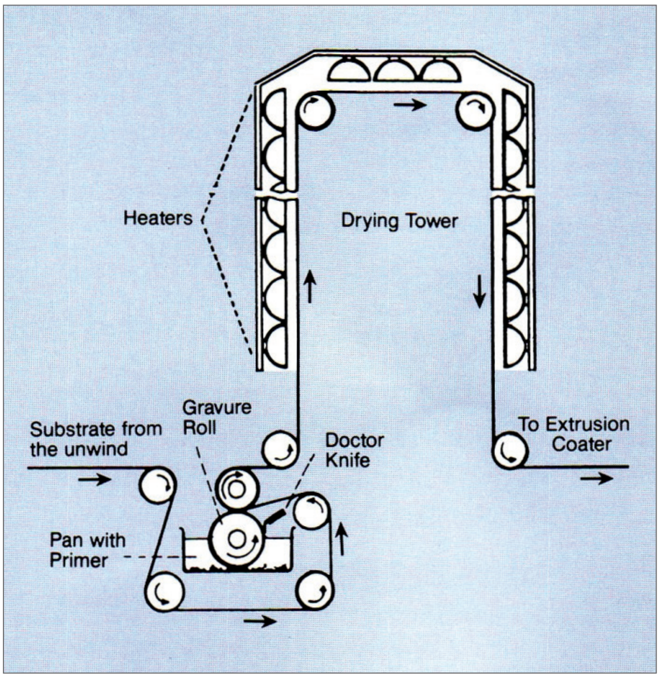

Figure 6: Schematic Drawing of Typical Priming Station

The most common priming systems are:

Polyurethanes	excellent with aluminium foil and plastic, very good with paper
Polyethylene imine	excellent with plastic films, very good with paper
Polyvinylidene chloride	excellent with paper and plastic film
Ethylene-acrylic acid copolymer and ionomer	excellent with paper and aluminium foil

The curing polyurethane systems generally offer the widest range of adhesion and the best resistance to heat, moisture and chemicals. The other primers all suffer limited resistance to these environments.

Electrical Surface Treatment

Corona discharge treatment enhances the adhesion of polyethylene to non-porous substrates. The treatment is applied to the substrate prior to its entry into the nip.

Corona discharge treatment is particularly effective with plastic films such as polyester and polyamide films, oriented and cast polypropylene, and to a lesser extent aluminium foils. It also has a beneficial effect with paper substrates.

Ozone Treatment or Ozonisation

Ozone treatment is a technique sometimes used to accelerate the oxidation of the polyethylene web, especially with high speed coating lines where natural oxidation is limited by the short time of the web in the air gap. A stream of ozone-rich air from an ozone generator is directed via an applicator slit onto the hot web just before it enters the nip. The ozone, being a very strong oxidising agent, creates polar groups on the polyethylene surface, and very effectively improves the adhesion. The effect is illustrated in Figure 1. Ozone treatment is mostly used in combination with either or both corona treatment and chemical priming.

The benefits of ozone treatment are:

- Improved adhesion
- Opportunity to reduce melt temperatures and hence reduce the possibility of odour issues
- Opportunity to run at higher line speeds, thus reducing production costs
- Opportunity to run lower air gaps whilst improving melt stability and neck-in performance
- Improved heat seal characteristics

In other words, ozone treatment improves adhesion and minimises the negative effects associated with excessive oxidation such as odour/taint, chill roll sticking and poor heat sealing.

It should be noted that ozone is a toxic gas at high concentrations. The web area should be enclosed and an adequate ventilation system installed to remove the ozone after contact with the web.

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