Qenos

04 EXTRUSION COATING & LAMINATION

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TECHNICAL GUIDE

Alkathene® Alkatuff®

Front Cover

Pellet geometry and pellet quality can have a significant effect on material flow and the efficiency of feeding polyethylene into an extruder. Qenos measures pellet quality using a pellet shape and size distribution analyser, a device that photographs around 10,000 pellets in 4 minutes, digitally analyses the images and generates a report on pellet quality.

EXTRUSION COATING AND LAMINATION

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4 EXTRUSION COATING AND LAMINATION

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INTRODUCTION

With the increasing trend towards more sophisticated packaging and industrial materials, laminated and composite flexible structures are being widely used for many applications. By combining the unique barrier, sealability and structural properties of several different substrates, a composite laminate is realised with the characteristics required for specialised packaging and industrial applications. Extrusion coating is one of the processes used to produce a large range of thin multilayer structures.

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INTRODUCTION

Extrusion coating is one of the processes used to produce a large range of thin multilayer structures. In the extrusion coating of polyethylene, a molten web of extruded polymer is applied as a thin coating onto a substrate which is passing continuously through a nip-roll assembly (see Figure 2). In extrusion lamination, the molten polymer is applied as an adhesive layer between two substrates to form a laminated structure. The substrate may be paper, paper board, polyester film, polypropylene film, aluminium foil, woven fabric, etc.

Low density polyethylene (LDPE) is especially suitable for use in the extrusion coating process and is applied to a wide variety of substrates as indicated in Appendix 1. A major application is in the coating of board for milk and fruit juice cartons, as an LDPE/board/LDPE or LDPE/board/adhesive/aluminium foil/LDPE laminate (the latter for aseptic packaging). Other applications include specialised laminates for liquid and food packaging, and industrial and building uses.

The polyethylene coating provides increased tear resistance, scuff resistance, a heat sealable surface, resistance against chemicals, grease resistance, and a good barrier against water and various gases.

Because of processing challenges, linear low density polyethylene (LLDPE) has had only limited application in extrusion coating and lamination and this is amplified in a section at the end of this publication (see pg. 15). However, its superior mechanical properties and sealability would be beneficial in many laminate structures.

GRADE SELECTION FOR EXTRUSION COATING

Alkathene LDPE grades are characterised mainly by their melt flow index (MFI) and density. The way in which these parameters affect the physical and chemical properties of the polyethylene is described in detail in the publication: General Properties.

- Note for convenience, the term Melt Flow Index or MFI is defined as the melt flow of polymer extrudate in g/10 min when subjected to a load of 2.16 kg – otherwise referred to as MI_2.

In general the MFI of *Alkathene* LDPE extrusion coating polymers is in the range 4 to 12 g/10 min and the density around 0.918 to 0.924 g/cm^3. The choice of the appropriate grade for a particular extrusion coating application is invariably a compromise between a number of conflicting requirements with regard to processing performance and laminate properties. Figure 1 indicates the influence of MFI and density on these various properties.

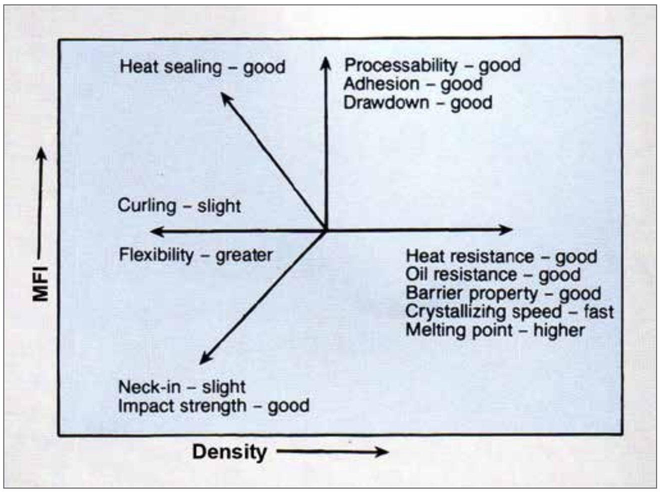

Figure 1: **Influence of MFI and Density of Low Density Polyethylene on Processability and Laminate Properties**

For example, good processability (drawdown) is obtained using a high MFI polymer but this is at the expense of neck-in performance during the extrusion coating process. Good flexibility is achieved using low density polymer but higher density is required for good heat and oil resistance and superior barrier properties.

Some of the effects of MFI and density on the extrusion coating performance and laminate properties are described in more detail later in this publication.

The properties of the finished laminate will depend not only on the grade of *Alkathene* LDPE resin selected but also on the substrate and the extrusion conditions used.

EXTRUSION COATING PROCESS TECHNOLOGY

The Extrusion Coating Process

In the extrusion coating process, polyethylene is melted under heat and pressure in an extruder and the molten polymer is extruded through a slit die as a thin web. This web, at high temperature, is drawn down and coated onto a flexible substrate in a nip-roll assembly formed by a water-cooled chill roll and a rubber-covered pressure roll. The substrate to be coated is fed continuously from an unwind reel over the rubber pressure roll into the nip where the laminate is formed by pressing the two layers together. The laminate is rapidly cooled by the chill roll and is taken up by a wind-up mechanism.

A schematic drawing of a typical extrusion coating line is shown in Figure 2.

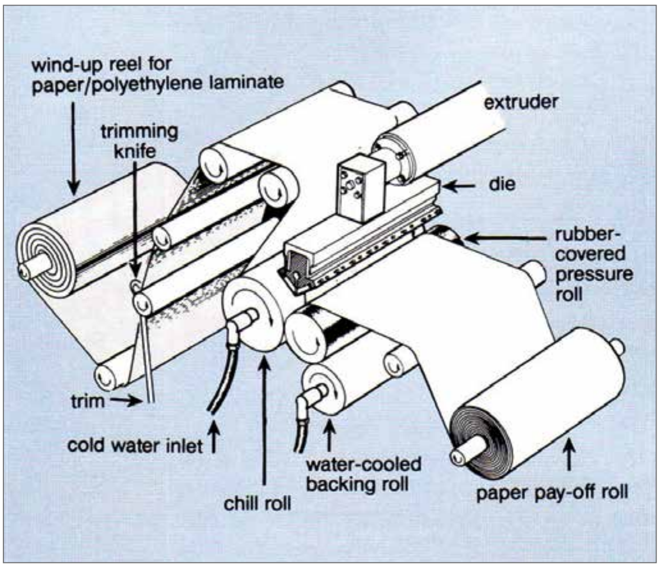

Figure 2: Typical Extrusion Coating Line for a Paper/Polyethylene Laminate

The Extruder

The purpose of the extruder is to deliver uniformly heated homogeneous melt to the die, at an acceptable temperature and rate. The general principles for the extrusion of *Alkathene* LDPE resins are described in the publication: Extrusion.

For extrusion coating, a single screw extruder is generally preferred with a screw length to diameter ratio of greater than 25:1. To facilitate die and extruder adjustment (especially for start-up and shut-down procedures), it is best to mount the extruder so that it can be moved away from the lamination and reeling equipment.

Good mixing of the melted polyethylene is essential if a good coating film with no defects or blemishes is to be obtained. Defects which may be apparent as a result of a non-homogeneous melt include:

Pinholes	tiny holes in the coating surface
Voids	small holes in the coating matrix
Lace curtains	large voids giving the coating the appearance of lace – this is often due to moisture or volatiles in the polymer
Streaks	thin bands in the coating extending in the machine direction and showing thicker and thinner areas of coating
Die lines	lines in the coating in the machine direction, often caused by contamination or oxidised particles in the die
Gels	round or elongated clear spots which are raised so that they can be felt
Oxidised particles	yellow-brown specks
"Applesauce" or "Orange peel"	rough, wavy appearance in the coating, reminiscent of applesauce or orange peel

All of the above defects are either detrimental to the appearance of the coating or damaging to the mechanical and barrier properties. Voids and lace curtains will result in a totally unacceptable product.

Pinholes will make the coating permeable to grease, chemicals, moisture, gases and vapours. Streaks, gels, oxidised particles or "applesauce" affect the coating's appearance and may indicate some form of contamination or inadequate operating conditions.

The Die

The slit die used in extrusion coating is normally centre fed, particularly when the die is wide; however, an end-fed design may also be used. The two main types of dies are the coat-hanger die and the T-slot manifold die.

The prime objective in an extrusion coating slit die is to have the melt leaving the die at constant velocity across the full width. When a centre-fed die is used the uniformity of the delivery rate across the die can be controlled by restricting the flow in the shorter flow-paths, or by maintaining the temperature at the die extremities 5 to 10°C higher than that at die centre. However, the latter does not always produce the best quality film.

Uniformity of flow is preferably achieved by contouring the internal die dimensions or by adjustable choke bars. Adjustable die lips give maximum adaptability of the die when in use. Adjustable deckle rods inserted at each end of the die permit adjustment of the effective width of the die.

The Air Gap

The air gap, or draw distance, between the die lips and the nip to chill roll contact point is one of the most important areas in terms of the polymer's coating performance. In the air gap, some of the properties of the laminate are most affected by extrusion conditions. It is here that the molten web is drawn down and necks-in (see pg. 8) and oxidation takes place.

A large gap may cause premature cooling of the melt, increasing its viscosity which in turn may lead to poor adhesion to the substrate. However, if the air gap is too small then this can also result in a deterioration of adhesion strength. V-shaped dies allow the die lips to approach close to the nip, thus minimising the amount of cooling and improving the control over the degree of adhesion.

Nip Assembly and Chill Roll

The nip (see Figure 3) is formed by the steel chill roll and the rubber-covered pressure roll. The chill roll is usually chromium-plated and highly polished, although matte and "mirror pocket" surface finishes are sometimes used. It is designed to remove the maximum amount of heat from the polyethylene, and its construction is usually based on a double-shell arrangement with built-in spiral baffles to ensure effective and regular cooling. The cooling medium is water, circulated from a separate storage tank in which it can be maintained at a set temperature. It is essential to provide sufficient water to ensure effective temperature control at the surface of the roll. The diameter of the roll, which is determined by the working speed range, must be large enough to significantly reduce the temperature of the laminate during its brief period of contact.

The temperature of the chill roll should be kept at approximately 15 to 30°C; if it increases to 55 to 60°C or higher, the polyethylene may stick to the chill roll, causing partial delamination between the coated web and the substrate, or even web breakage.

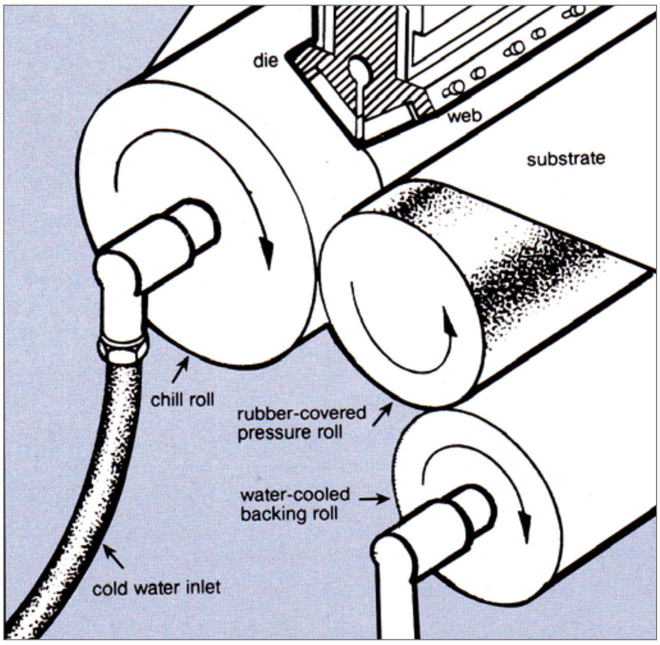

Figure 3: Typical Extrusion Coating Nip Roll Assembly

The rubber pressure roll is usually made from silicone rubber but neoprene rubber can also be used. The requirements of the pressure roll include that it needs to have good resistance to heat-ageing and work-hardening. The roll is actuated by air cylinders to exert an even pressure against the steel chill roll. It is also desirable to have provisions for continuous cooling of the surface of the pressure roll by having a water-cooled backing roll (see Figure 2).

The position of the nip is usually adjustable relative to the die. To obtain maximum adhesion the nip should be set to ensure that the molten polyethylene meets the substrate just before the chill roll exerts its cooling effect.

Edge Trimming

It is not possible to coat the molten web to the same width as the substrate, due to two different effects which modify the edges of the web. One of these effects is known as edge weave. The other is the thickening at the edges of the web to form an edge-bead. This is a consequence of the necking-in of the web between the die and the nip. To overcome these faults it is necessary to remove edge trim (consisting of polyethylene and/or substrate) continuously by means of slitting knives.

When a neoprene pressure roll is used the polyethylene cannot be applied beyond the edge of the substrate because it sticks to the neoprene. Polytetrafluoroethylene (PTFE) adhesive tape is often applied around the ends of the pressure roll to prevent sticking of the molten polyethylene, to improve the service life of the rubber covering and to allow extrusion of a wider web.

With a silicone-rubber pressure roll, the molten polyethylene has a lower tendency to stick, particularly if the roll is cooled by contact with a water-cooled chill roll. This allows the polyethylene to be applied beyond the full width of the substrate, so that only the excess needs to be trimmed.

Reeling and Wind-up Equipment

Equipment for the high-speed handling of reels of paper and other substrates is usually highly specialised and not designed to handle a range of materials. Static eliminators are always incorporated to dissipate any build-up of electrical charge. Information on reeling equipment is best obtained from the machinery suppliers.

Since the coating line must run continuously, flying-splice unwinds and rewinds are usually installed to permit automatic reel changes at full production speed.

Coextrusion

Coextrusion is often used in combination with extrusion coating/lamination. In coextrusion two or more layers of different polymers are extruded simultaneously through a single die. The major benefit of coextrusion is that some of the separate laminating steps required to produce a complex multilayer laminate can be combined into one step in the process.

There are two main types of coextrusion dies. The most popular is the feedblock die where several melt streams fed from separate extruders join within the die and are extruded as one web. With this die type, more than two different polymers can be extruded but their viscosities must be carefully matched. With the dual slit die, two extruders feed two separate channels in the die block and the two extruded webs meet at the nip where they are pressed onto the substrates. This die type is not widely used.

Coextrusion offers the possibilities of extruding a thin layer of an adhesion-promoting polymer or a tie layer, such as an ionomer or ethylene-acrylic acid copolymer, in combination with polyethylene. Tie-layers are generally used to bond two dissimilar materials (e.g. polyethylene and aluminium foil) together and to improve the adhesion. For many laminates, this may eliminate the need for chemical priming or other pre-treatments of the substrate.

Another application is the coextrusion of two polyethylene layers, one at a relatively high temperature to promote oxidation and adhesion to the substrate, the second extruded at a much lower temperature to give a top coating layer with better heat sealability and an acceptable odour level.

EFFECT OF PROCESSING CONDITIONS ON PROPERTIES

Melt Temperature

The exact conditions required to achieve optimum product quality will vary from one unit to another. However, coating weight uniformity, adhesion strength, and overall quality are largely dependent on the melt temperature and its uniformity.

The melt temperature used varies according to the substrate being coated, customer requirements regarding desired properties, and the equipment. Temperatures can be between 265 and 330°C but 300 to 320°C are typical.

Properties such as gloss and clarity improve with increasing operating temperatures. However, if the temperature is too high, the melt exiting the die may be too fluid for coating. It may also be difficult to cool and windup, and excessive oxidation may occur. Oxidation is a prerequisite for good adhesion, but can lead to inferior heat sealing and the possibility of odour and taint problems.

High temperatures can also lead to fairly rapid degradation of the polyethylene, especially in the extruder and die system if the process is stopped for longer than a few minutes. If thermal degradation is allowed to occur, the flow of the polymer will be adversely affected and undesirable defects and blemishes will appear in the coating. Shut-down and start-up procedures are therefore very critical.

Low melt temperatures on the other hand may give the polyethylene coating better frictional properties and allow heat sealing at greater speeds (shorter dwell time) and at slightly lower temperatures. This may be at the expense of adhesion.

Fluctuating or non-uniform melt temperatures may result in irregular coating gauge, uneven width, variable clarity and gloss, wrinkles in the finished roll, pinholes and other defects.

Coating Weight, "Neck-in" and "Drawdown"

The thickness of the coating is usually expressed in terms of the surface coverage or coating weight (see Table 1). Coating weights range from as low as 8 to 10 g/m^2 for packaging films and up to 50 to 100 g/m^2 for certain heavy duty cartons and fabric coatings. The coating weight is determined by the line speed (chill roll speed) and the extruder output rate. Line speeds usually range from 100 to 600 m/min but can be much higher for special applications.

Table 1: Surface Coverage for Polyethylene Coatings using a 0.920 g/cm^3 Density LDPE

	Surface Coverage	
Thickness μm	g/m^2	m^2/kg
10	9.2	108
25	23.0	43
50	46.0	22

Associated with coating weight are two important properties of the extruded web, "neck-in" and "drawdown".

- *"Neck-in"* is the reduction in width of the molten film web which occurs as it leaves the die. It is measured as half the difference between the width of the coating at the nip and the width of the die, as indicated in Figure 4. Neck-in is caused by surface tension and melt elastic effects in the immediate vicinity of the die exit.
- *"Drawdown"* refers to the ability of the polymer to coat evenly down to very low coating weights without breakage. It involves the reduction in thickness of the molten polyethylene after leaving the die and before contacting the substrate. It is a limiting factor in the maximum line speed obtainable.

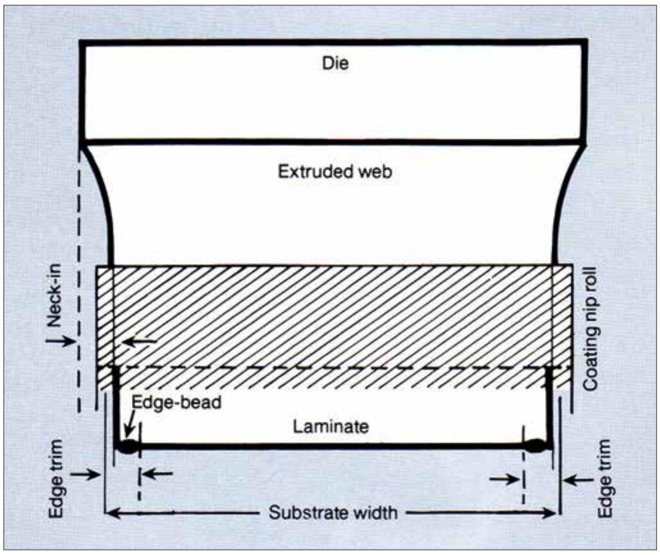

Figure 4: "Neck-in" During Extrusion Coating

It is important that extrusion coating grades of polyethylene have good drawdown, particularly if low coating weights are to be obtained without causing tear-offs and voids. Neck-in should be minimal to reduce trimming and obtain the maximum useable width of the laminate.

Neck-in and drawdown are a function of MFI and melt temperature. As shown in Figure 5, the maximum line speed (drawdown) increases with increasing MFI but neck-in performance gets worse. The choice of a coating polymer is thus a compromise between drawdown and neck-in performance. Most extrusion coating polyethylenes have an MFI in the range 4 to 12 g/10 min.

Other factors also play a role in determining neck-in performance and maximum drawdown. These are as follows:

- **Line speed.** Neck-in values decrease with increasing line speed (see Figure 6).
- **Processing temperature.** Neck-in increases and drawdown improves with increasing melt temperature (see Figure 7).
- **Air Gap.** Large air gaps give better drawdown but worse neck-in (see Figure 8).
- **Polymer swelling ratio.** (defined as the initial thickness of the polymer melt exiting the die over the die gap). Neck-in decreases but drawdown is worse as the swelling ratio increases.

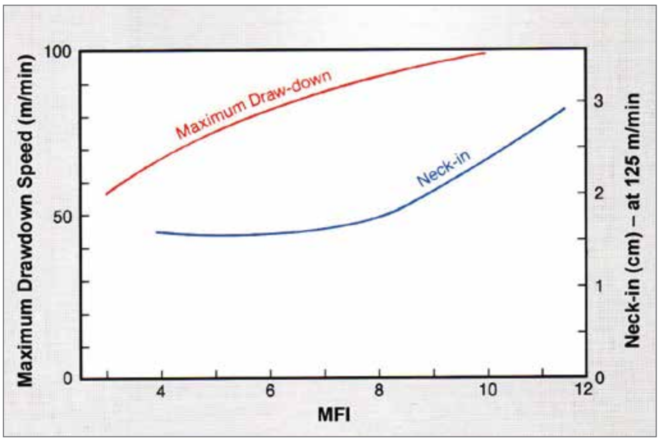

Figure 5: Variation of Drawdown and Neck-in Performance for *Alkathene* LDPE Resins of Different MFI

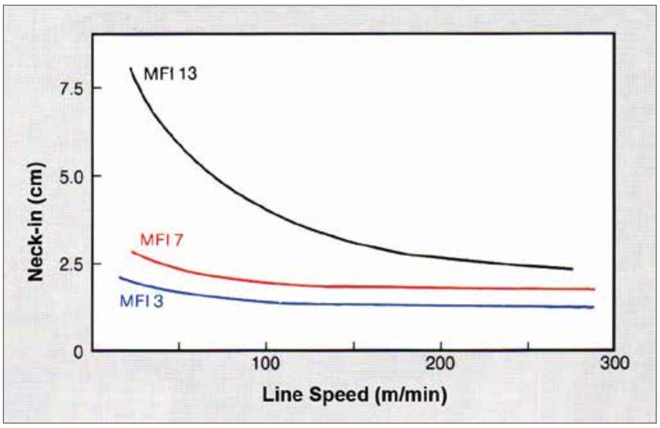

Figure 6: Effect of Line Speed on Neck-in for Several *Alkathene* LDPE Grades of Different MFI

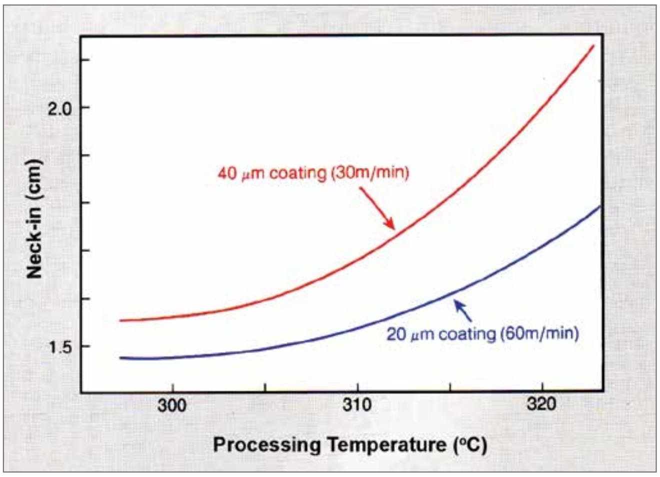

Figure 7: Effect of Processing Temperature on Neck-in

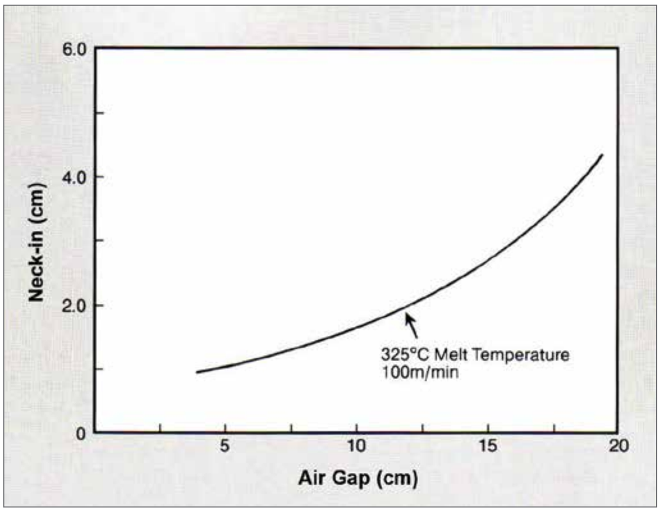

Figure 8: Typical Effect of Air Gap Distance on Neck-in

Edge tearing occasionally occurs during extrusion coating, and this is an indication that web breakage is imminent. Edge tearing can affect the width of the coating. It can be caused by cold die ends or a high draw ratio. Using a narrower die gap, increasing the coating weight (by decreasing the line speed or increasing the extruder output) or raising the temperature at the ends of the die can assist in overcoming this problem.

ADHESION

The Nature of 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 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 9.
- **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 10).
- **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 11).
- **The air gap.** A larger air gap allows more oxidation of the surface, thus promoting adhesion, as discussed earlier (see Figure 12).
- **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 13). As thinner coatings are extruded, they cool more in the air gap and adhesion may become poorer.

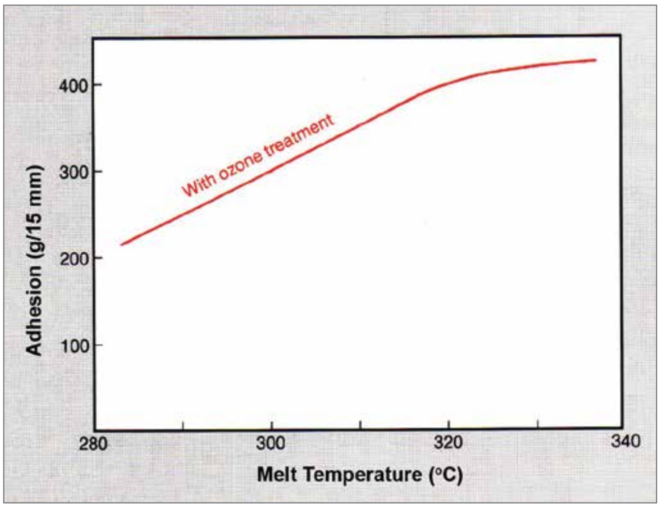

Figure 9: Effect of Melt Temperature and Ozone Treatment on Adhesion of Extrusion-Coated LDPE to Aluminium Foil

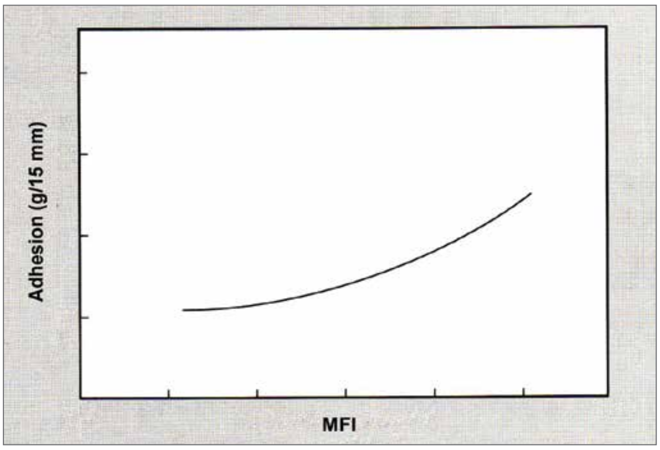

Figure 10: Effect of MFI on Adhesion of Extrusion-Coated LDPE to Porous Substrates

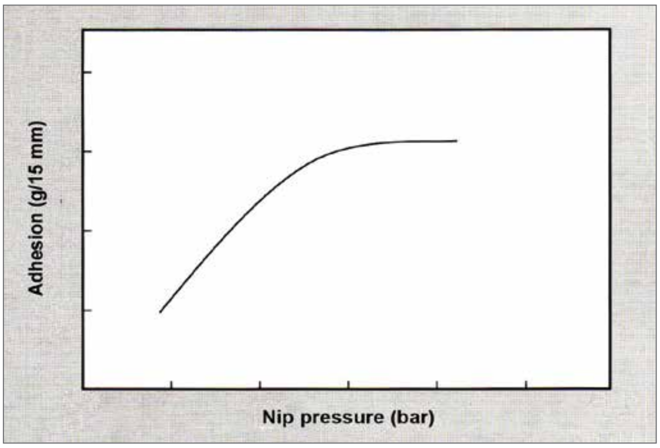

Figure 11: Effect of Nip Pressure on Adhesion of Extrusion-Coated LDPE to Porous and Non-Porous Substrates

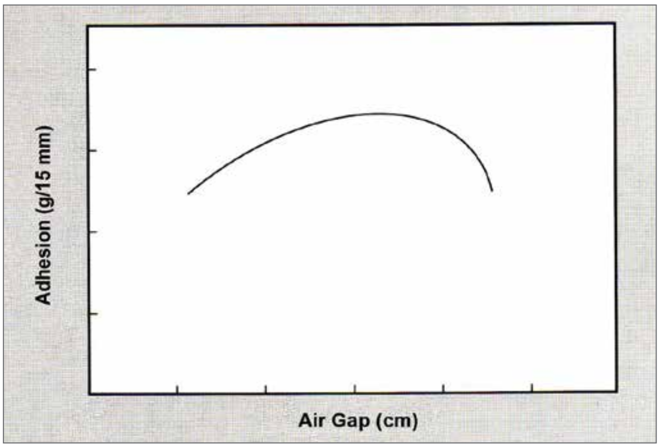

Figure 12: Effect of Air Gap on Adhesion of Extrusion-Coated LDPE to Non-Porous Substrates

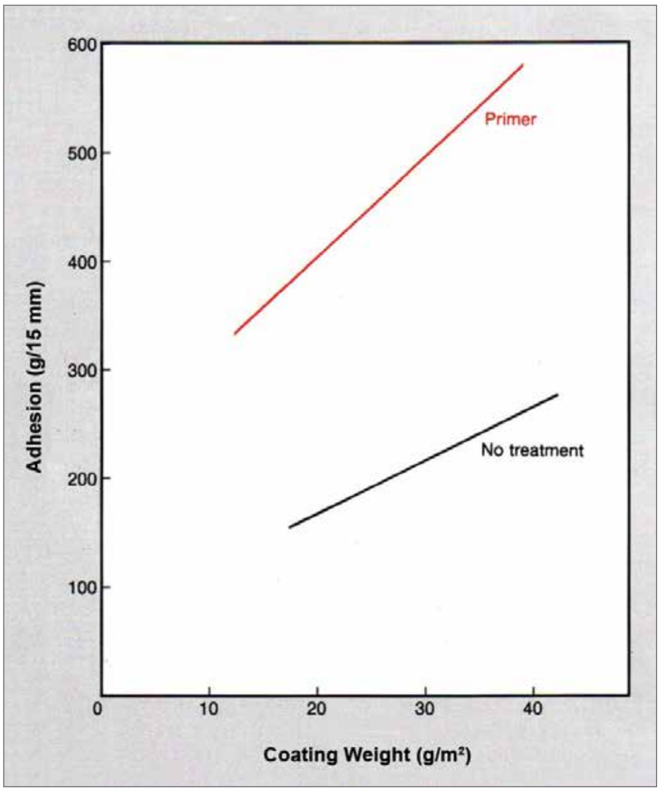

Figure 13: Typical Effect of Coating Weight on Adhesion of Extrusion-Coated LDPE to Aluminium Foil (60 m/min, 307ºC)

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 14 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.

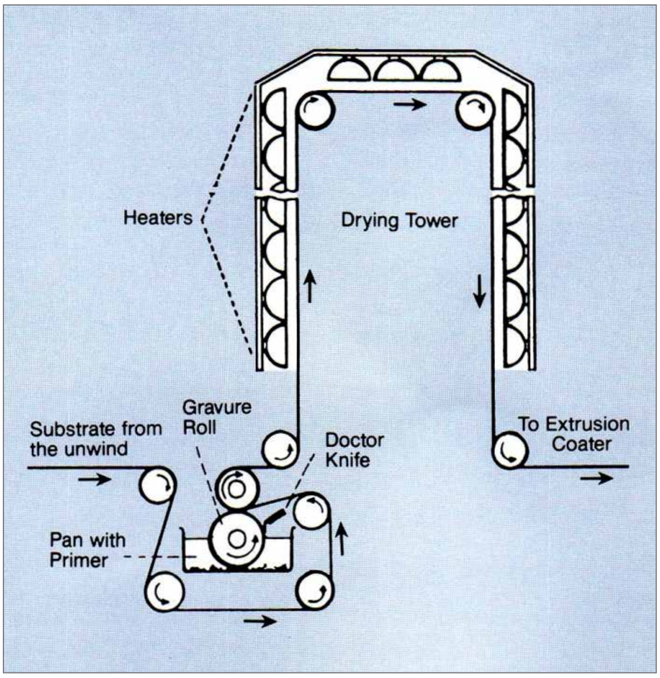

Figure 14: Schematic Drawing of Typical Priming Station

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 9. 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.

PROPERTIES OF EXTRUSION-COATED LAMINATES

Frictional Properties

One of the important final properties of the coated laminate is the ease with which it will slide or slip over another surface, i.e. its coefficient of friction (COF). A similar property is blocking, which is the tendency of adjacent surfaces in intimate contact to stick to each other, making separation difficult.

The COF and blocking of the coated polyethylene surface are affected by such factors as coating temperature, chill roll temperature, chill roll surface finish, overtreatment during corona discharge treatment, and of course, the presence or absence of slip and antiblocking additives in the polyethylene.

The use of different chill roll finishes allows the texture of the coating to be varied. There a three types of chill roll finish:

- A matte finish, which results in a rough surface on the polyethylene, a relatively low gloss, and a low COF (high slip).
- A highly polished mirror finish, which gives a very glossy coating and increases the COF.
- A "mirror pocket" finish, which induces some roughness on the surface and a low COF like that obtained with the matte roll, but with higher gloss like that from the mirror roll.

The COF decreases as the polymer density increases. It is relatively unaffected by the air gap distance but may decrease slightly at low melt temperatures. A high coating temperature and a highly polished chill roll can contribute to blocking. Increased chill roll temperature will increase slip and decrease blocking.

If a coated substrate is to have a glossy coating on both sides, then the use of a slip additive might be considered. The slip additive blooms to the surface and significantly reduces the COF. The effects of the additive on the taint of the product must be reviewed as part of the decision making process.

Heat Sealing

Polymer density, MFI, film thickness and sealing conditions all affect the "sealability" and the strength of the heat seal bond.

Density controls the minimum temperature at which sealing takes place and the amount of heat required to melt the polymer. Melting properties can be determined by Differential Scanning Calorimetry (DSC) on different grades, as shown in Figure 15. Density also has a minor influence on the ultimate heat seal strength. However, it should be noted that the density of the coating can be significantly affected by thermal history (rate of cooling) as dictated by the line speed and the chill roll temperature.

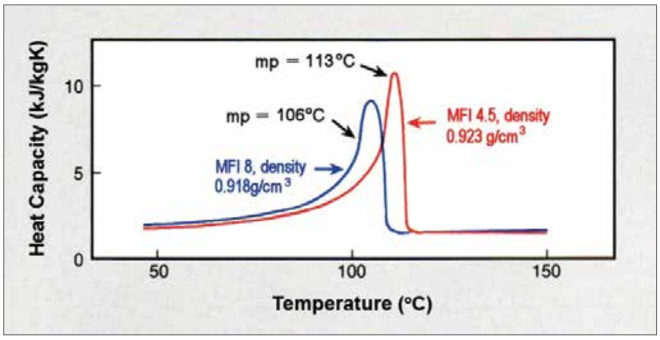

Figure 15: Melting Point and Heat of Fusion for *Alkathene* LDPE Extrusion Coating Polymers. (Determined by Differential Scanning Calorimetry)

The polymer MFI and the film thickness are the principal factors influencing the heat seal strength, as illustrated in Figure 16.

The strength of the seal while still hot is important particularly with high speed automatic filling and packaging machines, where the product is introduced into the package almost immediately after the seal has been formed. For instance, many paper board laminate seals are under tension, with the tendency to reopen when the sealing pressure is released. Sufficient melt strength is required to ensure that the seal remains intact until it cools. The hot tack strength is one measure of a polymer's performance in situations such as this. A strong bond over as wide a temperature range as possible is indicative of good performance.

Alkathene LDPE extrusion coating grades have good hot tack properties which are illustrated in Figure 17.

Excessive oxidation of the polyethylene surface can lead to difficult heat sealing. Such oxidation may occur in the air gap between the die and the nip, or during corona discharge treatment. However, some oxidation is necessary to promote bonding to non-porous substrates.

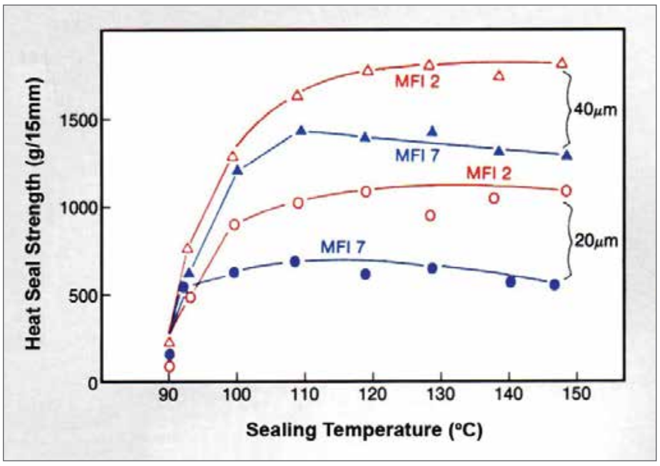

Figure 16: Relationship between MFI Values, Heat Seal Strength and Sealing Temperature

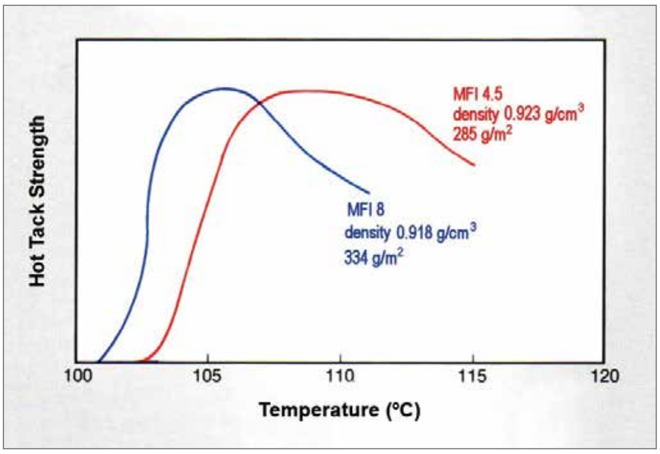

Figure 17: Typical Hot Tack Strength Characteristics of *Alkathene* LDPE Extrusion Coating Polymers.

Barrier Properties

An important function of any laminate is to provide a barrier against a variety of gases, vapours or liquids. Polyethylene generally provides a good to excellent barrier to such materials and the performance will usually improve as the density increases and the MFI decreases.

Improved barrier properties are also achieved as the coating weight is increased. However, it is often more satisfactory to incorporate in the laminate a material with a much lower intrinsic permeability, such as polyester film, polyvinylidene chloride film or aluminium foil. In such laminates the polyethylene can still provide one or more of the following functions:

- Tear or puncture resistance
- Adhesive layer between two other films
- Heat sealability

Table 2 illustrates typical gas water vapour transmission rates through various 25 micron packaging films. Further information about the permeability of films is given in the publication: General Properties.

Food Contact – Odour and Taint

Alkathene LDPE extrusion coating polymers are suitable for use as polymer coatings in contact with foodstuffs. They meet the requirements set down by the US Food and Drug Administration (FDA) – 21 CFR 177.1520 (c) 2.1 and the Australian Standard AS2070- Plastics Materials for Food Contact Use.

Alkathene LDPE extrusion coating polymers have been used over many years to give coatings of very low odour and taint; they are components of laminates used to package a wide variety of foodstuffs including milk, fruit juices, dried soups, etc.

Odour and taint are often caused by additives in the polymer or by excessive oxidation of the polymer at the high temperatures used for extrusion coating. *Alkathene* LDPE extrusion coating polymers are additive free. If optimal processing temperatures are applied for these polymers, then the problems from excess oxidation should not arise. However, tolerances are fairly tight and should be closely monitored at all times.

There is no apparent relationship between odour or taint of the coating and parameters such as density and MFI.

Table 2: Relative Gas and Water Vapour Transmission Rates of Polyethylene and Other Packaging Films

Film	Gas Transmission Rate (for 25 micron film at 20°C, 1 atm) (cm^3/m^2, 24 h)			Water Vapour Transmission Rate (for 25 micron film at 38°C, 90% RH.) (g/m^2, 24 h)
	O_2	N_2	CO_2	
Polyethylene LDPE (0.920 g/cm^3)	8500	3000	38000	18
Polyethylene HDPE (0.960 g/cm^3)	3000	650	9000	8
Ethylene Vinyl Acetate EVA Copolymer (18% VA)	12000	6200	45000	70
"Surlyn" ionomer	6500	–	6500	30
Polypropylene Biaxially oriented	1900	500	5500	6
Polypropylene PVdC coated BOPP	16	4	30	6
Polypropylene, cast	4200	750	10000	12
Polyethylene Terephthalate (PET)	60	15	250	25
Biaxially oriented nylon	20	–	–	180
Polyvinylidene Chloride (PVDC)	15	3	50	3.5
Ethylene Vinyl Alcohol* EVAL-E	1.8	0.15	7	–

* Moisture dependent

Printing and Gluing

If polyethylene-coated surfaces are to be printed with inks or glued by an adhesive, a degree of oxidation of the polymer surface is necessary to cause the ink or adhesive to adhere. The oxidation can be obtained either by suitable adjustment of the air gap or preferably by using corona discharge treatment. Treating is best carried out in-line in order to minimise handling of the coated rolls.

Polymers containing slip or antiblock additives must be treated in-line before the additive has time to bloom to the surface of the coating.

ALKATUFF LLDPE FOR EXTRUSION COATING

Introduction

Linear low density polyethylene (LLDPE) is generally not suitable for use in the extrusion coating process. LLDPE has poorer processability in the extrusion coating process due to its intrinsic rheological behaviour. However, many of the properties of LLDPE would be beneficial for extrusion-coated products, and these benefits are likely to be achieved through the use of blends of LDPE and LLDPE. Compared with LDPE of equivalent MFI and density, the superior properties of LLDPE include:

- Excellent sealability
- Excellent hot tack performance
- Superior tear resistance
- Greater abrasion resistance
- Improved adhesion onto aluminium and polyester
- Slightly lower water vapour transmission rate
- Higher softening point and heat resistance
- Higher drawdown, lower gauges possible

Draw Resonance

The main reason for the limited use of LLDPE in extrusion coating is the problem of draw resonance which occurs during the extrusion coating process above a critical flow rate. Draw resonance is a surging or sustained cyclic pulsation in the dimensions of the extruded web occurring between the die and the nip. It can result in wide variations in the coating thickness and the coating width, and consequently can cause a major deterioration in the product quality.

Draw resonance typically occurs with linear polymers because of their non-strain-hardening (or strain-thinning) characteristics in extensional flow. Conventional LDPE polymers like *Alkathene* show an increase in extensional viscosity with deformation and any disturbances in the flow, such as an instantaneous thinning, tend to be self restricting and stabilising. With LLDPE polymers like *Alkatuff*, the extensional viscosity shows a much reduced tendency to strain-harden and any disturbances will propagate and create instabilities, which in the case of extrusion coating is the phenomenon of draw resonance.

This difference in behaviour during extensional flow between *Alkathene* LDPE and *Alkatuff* LLDPE polymers is a consequence of the narrow molecular weight distribution and linear (no long chain branching) molecular structure in *Alkatuff* LLDPE compared with a wider molecular weight distribution and significant long chain branching with *Alkathene* LDPE.

Further information about the rheological differences between *Alkathene* LDPE and *Alkatuff* LLDPE is given in the publication: General Properties.

Draw resonance can be reduced by extruding at higher melt temperatures, and at higher output rates and lower drawdown speeds (to give a lower drawdown ratio and thicker coatings).

Other Coating Characteristics

The extrusion of *Alkatuff* LLDPE grades is more challenging than with *Alkathene* LDPE grades because of their higher shear viscosity at extrusion shear rates. This means that more extrusion power is required, greater melt temperatures and pressures are developed, and as a consequence, output rates may be limited. Special screw designs and dies with wider gaps are recommended. Further information is given in the publication: Extrusion.

Alkatuff LLDPE products have lower melt elasticity (and die swell) than *Alkathene* LDPE products and this is a serious limitation in extrusion coating, where high melt elasticity is a requirement for low neck-in performance. Accordingly, LLDPE polymers give high neck-in results. On the other hand, because of the lower extensional viscosity and melt strength of *Alkatuff* LLDPE products, its drawdown is excellent, thus allowing lower coating thicknesses.

APPENDIX 1 – TYPICAL LAMINATED FILMS

Construction	Benefits	Application
PE/kraft	Strong, water-proof, heat sealable, low cost with excellent moisture resistance.	From heavy to light duty packaging. Used in frozen foods, agricultural and fishery products and other foods.
PE/kraft/PE /kraft/ PE/kraft	Strong, water and moisture proof, chemical resistant, good gas barrier properties.	Heavy duty packaging only (fertilizer, fodder, cement, agricultural and industrial chemicals, sugar, salt and grains).
PE/high quality paper	Moisture proof, low cost and heat sealable. Good printing surface.	Light duty packaging. Simple moisture proof packaging for pharmaceuticals, moisture-absorbing foods and ready-to-serve foods.
PE/glassine	Moisture-proof, good oil and chemical resistance, semi- transparent and heat sealable.	Light duty packaging for oiled foods, pharmaceuticals, candies and machine parts.
PE/Al foil	Excellent moisture barrier, gas barrier, UV light barrier, outstanding fragrance preservation and heat sealable.	Light duty packaging for pharmaceuticals, candies, photo film packaging, industrial parts and machine parts.
PE/Al foil/high quality paper, PE/Al foil/kraft, Al foil/PE/Al foil, PE/high quality paper/Al foil.	Perfect moisture and gas barrier, chemical resistance, heat sealable, light shading and adaptable for automatic fill packaging. Good printing surface.	Light packaging for moisture-absorbing foods, detergent, candies, photo sensitive paper, photo films, spices and food additives.
PE/Cast polypropylene PE/Oriented polypropylene	Heat and oil resistance, moisture barrier, water proof, see-through and heat sealable.	Light packaging for pharmaceuticals, candies, oiled foods, moisture absorbing foods, table salt, sugar, seasoned foods, preserved foods and medical supplies.
PE/polycarbonate	Outstanding heat and oil resistance, moisture and water proof, outstanding for low temperature properties, see- through, excellent gas barrier and heat sealable.	Light packaging for seasoned foods, preserved foods, frozen foods. Also used in gas-fill-packaging and vacuum packaging for heat sterilisation.
PE/polyester	High strength, water proof, moisture proof, gas barrier properties, outstanding low temperature properties, see- through and heat sealable.	Light packaging for seasoned goods, preserved foods, processed meat, frozen foods, medical supplies and ready-to-serve foods. Also used for vacuum packaging for heat sterilisation and gas-fill packaging.

APPENDIX 2 – EXTRUSION COATING TROUBLESHOOTING GUIDE

Problem / Issue	Cause(s)	Potential Solution(s) /Action(s)
Adhesion	Low melt temperature	Increase the melt temperature to help oxidise the surface and prevent premature cooling Increase back pressure in the extruder
	Air gap too low	Increase the air gap to get adequate oxidation of the surface
	Line speed too high	Decrease the line speed to allow additional time in the air gap for oxidation of the surface
	Substrate surface untreated	Pre-treat substrate (such as corona treatment, flame treatment and ozonation) or add a chemical primer to improve wettability
	Pre-treatment ineffective	Inspect treatment method, adjust treatment settings as required, ensure primer coverage is adequate and drying time is sufficient
	Sticking to chill roll	Decrease the chill roll temperature
	Low nip roll pressure	Increase the pressure of nip rolls, ensure pressure is evenly distributed
	Air gap too high	Decrease the air gap to avoid premature cooling
	Low chill roll temperature	Increase the temperature of the chill roll to help overcome quick cooling
	High melt temperature	Decrease the melt temperature to avoid thermal degradation, decrease back pressure in extruder
	Surface active additives (e.g. slip)	Modify the additive package
	Inadequate resin selection	Ensure resin is compatible with substrate, lower viscosity (high melt index) resins adhere better to porous substrates
Apple sauce	High melt temperature	Decrease the melt temperature
	Inadequate mixing or poor melt quality	Increase the back pressure of the extruder and use finer screen packs
	Interfacial instability in coextrusion	Check flow properties of resins
	Contamination	Ensure adequate purging time and cleaning of transfer lines Check resin for any foreign material
Die Lip Build-Up	Additives	Modify the additive package
	High melt temperature	Decrease the melt temperature to avoid thermal degradation
	Melt scraping against die lip	Machine the die lip Change angle at which the melt contacts the chill roll
	Excessive resin shear	Lower output Increase the die lip temperature Increase the die gap
Draw Resonance	High draw ratio	Decrease the die gap Increase the coating weight
	High melt temperature	Decrease the melt temperature
	Melt strength of polymer is too low	Select higher melt strength resin
Edge Tear	High draw ratio	Decrease the die gap Increase the coating weight
	Low melt temperature	Increase the melt temperature
	Incorrect deckle settings	Decrease the off-set between internal deckle settings
	Inadequate die design	Seek advice from manufacturer

Problem / Issue	Cause(s)	Potential Solution(s) /Action(s)
Edge Tear continued	Melt strength of polymer is too high	Select lower melt strength resin
	Splicing	Reverse splice direction, seek advice from machine manufacturer
	Melt index too low for coating weight	Use higher melt index resin
Gauge bands	High melt temperature	Decrease the melt temperature to increase melt viscosity
	Dirty die	Clean the die to remove any build-up of material
	Variation in temperature control	Check the temperature zones are running correctly and use flat temperature profile
	Inadequate die set-up	Adjust the die bolts accordingly
	Poor melt quality	Increase the back pressure of the extruder and use finer screen packs
Gels and voids	Moisture	Check raw materials for moisture (e.g. resin and substrate) Ensure storage conditions are dry
	Degradation of polymer	Decrease the melt temperature Check temperature zones are running correctly
	Contamination	Ensure adequate purging time and cleaning of transfer lines Check resin for any foreign material
	Inadequate mixing	Increase the back pressure of the extruder and use finer screen packs
	Dirty die	Clean the die to remove any build-up of material
Neck-in	High melt temperatures	Decrease the melt temperature
	High draw ratio	Decrease the air gap Increase the coating weight
	Melt strength of polymer is too low	Select higher melt strength resin
Odour/Taint	High melt temperature	Decrease the melt temperature to reduce thermal degradation
	Air gap too high	Decrease the air gap to reduce the time for oxidation of the surface
	Additives	Modify the additive package
Pinholes	Substrate roughness	Use flame treatment on the substrate
	High melt temperature	Decrease the melt temperature
	Low coating weight	Increase the coating weight
	Dirty or damaged idler rollers	Inspect and clean the idler rollers or replace if necessary
	Excessive tension	Decrease the tension accordingly
Sealability	High melt temperature	Decrease the melt temperature to reduce thermal degradation
	Air gap too high	Decrease the air gap to reduce the time for oxidation of the surface
	Additives (e.g. slip)	Modify the additive package as some additives may bloom to the surface and contaminate the seal
	Inadequate sealing conditions	Increase the sealing temperature or dwell time
	Contamination	Clean the chill roll surface and limit handling of coating surface
	Inadequate resin selection	Use higher melt index resin
	Excessive corona treatment	Check treatment level and adjust if necessary
Surging	Inadequate screw design	Seek advice from manufacturer, increase back pressure in extruder
	Inconsistent hopper feeding	Decrease the temperature at the feed zone to stop bridging

Disclaimer

The proposed solutions in this guide are based on conditions that are typically encountered in the manufacture of products from polyethylene. Other variables or constraints may impact the ability of the user to apply these solutions. Qenos also refers the user to the disclaimer at the beginning of this document.

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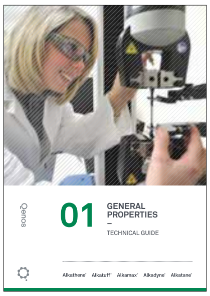

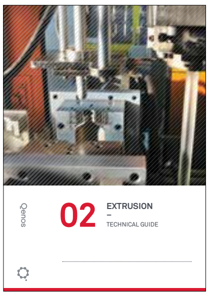

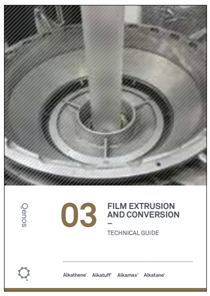

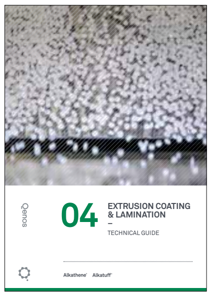

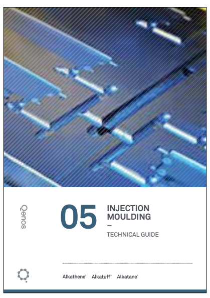

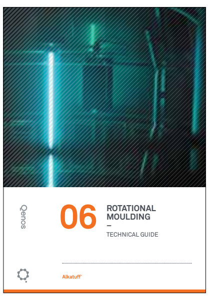

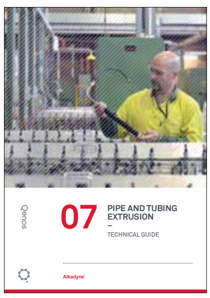

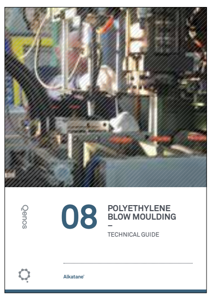

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