PACKAGING MATERIALS

9. MULTILAYER PACKAGING

FOR FOOD AND BEVERAGES

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REPORT

Commissioned by the ILSI Europe Packaging Materials Task Force

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PACKAGING MATERIALS:
9. MULTILAYER PACKAGING
FOR FOOD AND BEVERAGES

By John Dixon

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Author: John Dixon, Consultant (UK)
Scientific reviewers: Roland Franz, Fraunhofer Institute (DE), Mark Vints, Amcor Flexibles Europe (BE)
Report Series Editor: Kevin Yates (UK)
Coordinator: Tanja Wildemann, ILSI Europe (BE)

INTRODUCTION

*T*he last 50 years have seen major changes in the way that food is produced and retailed. Self-service supermarkets have grown to dominate the market, with a corresponding growth in pre-packaged food. More food is prepared before retail sale, even to the extent of ready-to-eat dishes. Such food production has become concentrated into fewer sites, with more products being distributed and marketed on a pan-European basis. At the same time, there has been a significant reduction in the number of food manufacturers and retailers.

These changes have driven an increasing sophistication in food packaging. Self-service demands products that stand out on the supermarket shelf. Consumers place increasing value in being able to see the product they are buying and in the freshness of the food at the time of purchase. Processed and part-processed foods require new packaging techniques to achieve an adequate shelf life. The concentration of food production facilities results in longer distribution lines and thus creates a need for packaging that can extend the shelf life, especially for fresh and chilled products. The fewer but larger manufacturers and retailers have driven down packaging costs by using better pack design, thinner materials and faster, more automated packaging processes.

These changing requirements for packaging have become more and more difficult to achieve with single materials. To achieve the required performance it has become necessary to combine the properties of different materials. This report deals with the way in which multilayers achieve this.

The report includes both flexible and rigid multilayer packaging. It does not cover:

- Metal packaging, which was the subject of the seventh report within the ILSI Europe Report Series on Packaging Materials.

- The contribution of printing inks, which are covered by the eighth report in the ILSI Europe Report Series on Packaging Materials.

- Two-component packs, i.e. those consisting of two different materials but that can exist separately, e.g. bag-in-box as used for breakfast cereals, labels applied to bottles and other containers.

PACKAGE DESIGN REQUIREMENTS

The use of multilayer materials is driven by the need to design a pack that combines different functional requirements.

Collation

A package must collate and contain the food. To do this, it may need:

- *Strength*. This term covers a number of properties. Examples include resistance to puncture, impact and tear.

- *Sealing*. The pack must be closed by some means. Traditional techniques such as tying, taping or gluing have largely given way to materials that can be sealed to themselves.

- *Dead-fold*. A pack may be formed from a material that stays folded when creased, with or without additional sealing.

Preservation

Very importantly, the packaging must help preserve the food, protecting it from external influences that could cause a deterioration in quality:

- *Moisture*: The moisture content of many foods must be controlled. For example, breakfast cereals will absorb moisture from the atmosphere to become soft. Bread will lose moisture to become dry. In such cases, packaging materials are required to provide a barrier to the transmission of water vapour in or out of the pack. Different materials have different permeabilities to moisture, which are expressed as water vapour transmission rates (WVTR) with units of $g/m^2/day$. Because transmission rates vary with both temperature and relative humidity (RH), these parameters must be defined for a given WVTR value.

- *Oxygen*: Most foods are susceptible to exposure to oxygen. For example, fats can be oxidised to produce off-flavours. Fruit juices can lose vitamin C or become discoloured. The technique of modified atmosphere packaging (MAP) is used to extend the shelf life of foods such as fresh meat and fish, creating a pack environment where the ratio of atmospheric gases has been altered in order to reduce microbial activity and spoilage. In such cases, the packaging material must provide a barrier to gas transmission. Oxygen transmission rates (OTR) are generally used to measure permeability and are expressed as $cc/m^2/day/bar$. Again, the temperature and RH must be specified. Other gases, e.g. carbon dioxide and nitrogen, have different transmission rates but these are often in proportion to the OTR (with CO_2 typically migrating through a material faster than O_2, and N_2 slower).

- *Light*: Both visible or UV light can be an initiator of oxidative reactions. For some foods, it is important that the packaging materials provide a physical light barrier to prevent light-induced changes in flavour or nutritional quality.

- *Other flavours, odours and chemicals*: A barrier to flavour, odour and chemicals can be important to prevent the food absorbing unwanted odours or substances from the outside environment. It is also needed to prevent flavour loss during storage.

- *Seal quality*: The way the pack is closed or sealed must match the barrier properties of the materials. A low-barrier pack will not need hermetic seals. However, a pack made from high-barrier materials must also have high quality, leak-free seals. This is particularly important when there is a requirement to prevent microbial contamination or in the case of MAP. At the most basic level, a pack must keep the food as clean and hygienic as it was when packed. However, if the food has been sterilised or pasteurised by in-pack heat treatment or by aseptic processing, it is vital that both the packaging material and the seals prevent micro-organisms from entering the pack.

Promotion

The appearance of a pack is important to attract the consumer and to present a quality image that is consistent with that of the product it contains. Print plays a major role in this as well as providing statutory and other information, but the packaging materials also play a part. They can be required to protect the ink from abrasion or to provide high gloss or matt finishes. White, coloured or metallic materials can provide a background for the ink.

The rigidity of a material can be important to allow it to stand up on the shelf and prevent it looking creased and "tired".

Machineability

Food is packed on high speed automated machinery. Efficient operation requires the use of packaging materials with precisely defined characteristics. Different machines make different demands on the material. A comprehensive list is beyond the scope of this report but examples of required characteristics include:

- *Tensile strength* to prevent stretching or snapping.
- *Softening or melting* when heated to provide a sealing medium.
- Conversely, *heat resistance* to prevent stretching or other damage during the sealing operation.
- *Rigidity, pliability or dead-fold* to allow the shape of a pack to be formed.
- *Slip*, e.g. to allow materials to pass over static machine parts – or lack of it, e.g. to allow materials to be gripped firmly or to be stacked.

Convenience

Ideally, the package will include design features that make it easier for the consumer to handle, to open easily and, in some cases, to reclose. Another focus is on design elements that help in the preparation of the food, e.g. steam valves for microwave reheating, susceptors, boil-in-bag packaging, etc.

Cost

There is a continuous pressure from food manufacturers and retailers to reduce packaging costs, both of the materials themselves and of the packaging operation. This forms a major design requirement for all packs.

Increasingly, the industry is not just thinking in terms of the monetary costs of packaging but also of its environmental impact. This issue is discussed further in the chapter on Environmental Aspects.

Food safety

As will be discussed more fully in the chapters on Regulatory Aspects and Safety Evaluation, the package must be designed so as to ensure the safety of the eventual consumer of the packed food and to comply with all food contact and other legal requirements.

THE PROPERTIES OF DIFFERENT MATERIALS

*I*n many cases, it is not possible to meet all the packaging design requirements using a single monolayer material. The whole rationale for the use of multilayers is to create a single packing structure that will combine the different properties of different base materials in order to meet these design requirements. This chapter gives some examples of these properties, albeit in general terms rather than quoting precise specifications.

As has been mentioned, a barrier to moisture and gases such as oxygen is needed for many packs. The different barriers provided by some commonly used base materials are illustrated by Figure 1, which shows their permeabilities to water vapour and oxygen.

Figure 1. Permeabilities to water vapour and oxygen of some base materials
Source: Typical values taken from industry data sheets.
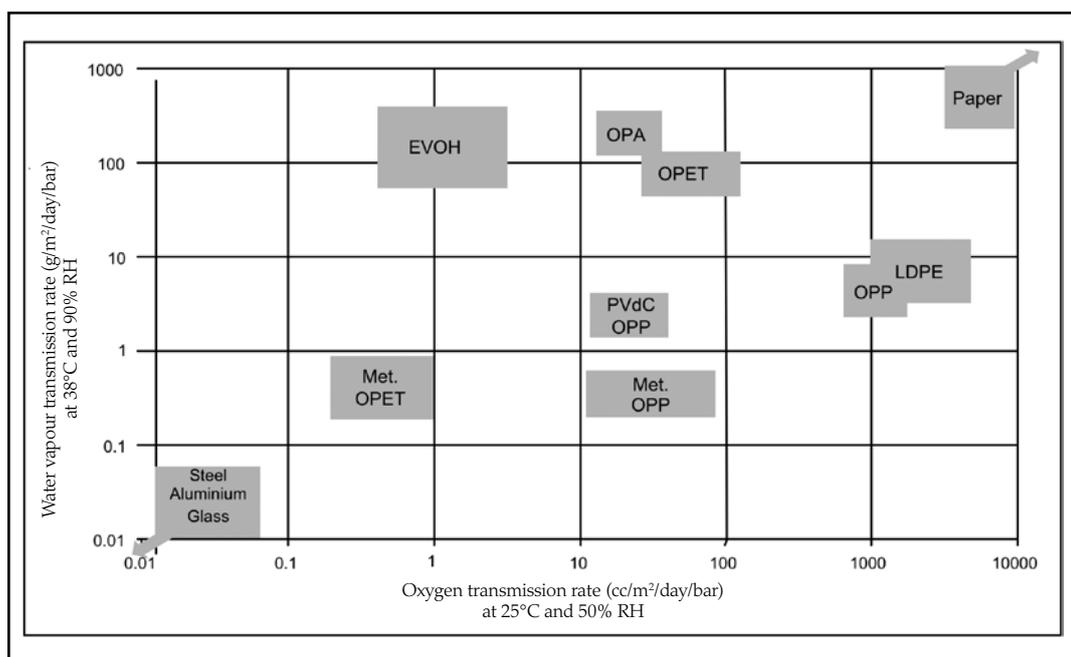
Note that log scales have been used. WVTR values are given in tropical conditions of 38°C and 90% RH, an industry standard. In normal ambient conditions (23°C and 50% RH) the actual WVTR would be about 75% lower.

Note that the above values are only illustrative and the actual permeability will depend on the precise grade, thickness and the final structure in which the material is used. Material thicknesses used for the examples are shown in Table 1.

The size of the boxes for each material approximately indicates the range of barrier properties possible, using different grades and thicknesses. It will readily be seen that moisture barrier and oxygen barrier do not go hand in hand. For example, metallised OPP with a WVTR of <1 g/m²/day has a good moisture barrier but only a moderate oxygen barrier (OTR of 10–100 cc/m²/day/bar). EVOH has less moisture barrier (WVTR of 50–200 g/m²/day) but much better oxygen barrier (OTR around 2 cc/m²/day/bar). It should be noted that, for this material, OTR is noticeably dependent on its moisture content and hence the RH.

Table 1. Typical thickness of some commonly used base materials

Abbreviation	Material	Thickness (microns)
Met. OPP	Metallised oriented polypropylene	20
Met. OPET	Metallised oriented polyethylene terephthalate (polyester)	12
LDPE	Low density polyethylene	25–100
OPP	Oriented polypropylene	15–50
OPA	Oriented polyamide	12–30
OPET	Oriented polyethylene terephthalate (polyester)	12–50
PVdC OPP	Polyvinylidene chloride-coated oriented Polypropylene	32
EVOH	Ethylene vinyl alcohol	2–10

For polymers, transmission rates are inversely proportional to the layer thickness. For multilayers, the total transmission rate can be calculated in good approximation by reciprocal addition of the transmission rates of individual layers, i.e. $1/TR_{(multilayer)} = 1/TR_{(layer1)} + 1/TR_{(layer2)} + ….$ Note that such considerations do not apply to thin coatings of polymers or to non-polymers. In these cases, the continuity of the coating or the presence/absence of pinholes might be more important in determining transmission rates.

Table 2 compares some other properties of a selection of web materials. In the example below, the more pluses, the better the material displays that property. Or in the case of "Cost", the more expensive it is. "0" indicates a complete lack of the property.

Table 2. Comparison of properties of web materials

Material		Tensile strength[1]	Light barrier	Heat sealing	Heat resistance	Dead-fold	Relative cost[2]
40–70 g/m²	Paper	+++	+	0	++++	++	++
6.3–12 µm	Aluminium foil	+	++++	0	++++	++++	+++
15–30 µm	OPP film	+++	0	0[5]	++	+	+
15-20 µm	Met. OPP film	+++	+++	0[5]	++	+	++
12–19 µm	OPET film	+++	0	0[5]	+++	+	++
12 µm	Met. OPET film	+++	+++	0[5]	+++	+	++++
12–20 µm	OPA film	++++	0	0[5]	+++	+	++++
30–70 µm	Blown LDPE film[3]	+	0	++++	+	+	+++
40–70 µm	Cast PP film	++	0	++++	+	+	++++
3–10 µm	EVOH layer[4]		0	0	+	+	+++

1 Strength is compared at the actual thicknesses indicated.
2 Relative cost is compared for thinnest grade mentioned.
3 In this case, "LDPE" includes not only low density polyethylene but also linear low density polyethylenes and copolymers with vinyl acetate etc.
4 Would not be used on its own; must be supported by other layers made of different resins. The relative cost reflects this.
5 Based on monolayer films; coextruded or coated films could be heat-sealable.

Tensile is only one measure of strength; for other measures, such as resistance to puncture, impact or tear, the relative performances will be different.

The light barrier scores for the films are based on transparent, unpigmented films. Incorporating pigments such as titanium dioxide increases opacity to be comparable with that of paper. The use of black pigments results in films with a light barrier similar to that of the metallised films.

THE RATIONALE FOR MULTILAYER STRUCTURES

Combining the properties of materials

When the design requirements for a pack demand two or more properties that cannot be found in a single material, there are two ways of proceeding.

Firstly, the pack can be made of two components, each one contributing at least one of the desired properties. For example, a bag based on 40 μm HDPE provides the moisture barrier needed to keep a breakfast cereal crisp throughout its shelf life. However, it lacks the rigidity to prevent the cereal from being crushed when stacked for transport, to enable the pack to stand up on a supermarket shelf, and to be easy to handle. The addition of an outside carton box provides these properties. By itself, the carton would lack the necessary moisture barrier. Such two-component packs are often the most cost-effective way to combine properties, especially if the thicknesses of materials required to provide the properties means that they are easy to handle on their own. Such packaging is not covered by this report; information on the individual mono-materials is given in other ILSI Europe Reports, which cover paper and board (Packaging Materials 6) and the most commonly used plastics (Packaging Materials 1–5).

This report looks at the second approach, whereby two or more components are combined to make a multilayer material. The following examples illustrate why and how this is done.

Heat-sealable coextruded oriented polypropylene film

Table 2 shows that OPP is one of the lowest cost packaging materials. Hence, it is well suited to the task of over-wrapping a tray containing foods such as bread rolls, croissants or cakes, where there is a moderate requirement for water barrier to prevent the food drying out for its shelf life of a few days. OPP is also glossy and transparent, giving an attractive sparkle to the pack and allowing the consumer to see the product. The high-speed horizontal form-fill-seal machines used for efficient packaging of this type of product require a heat-sealable film. However, the orientation process that is used to make OPP thin – and hence low cost – results in a film that shrinks before it can heat-seal.

To add this capability, a multilayer structure is used. A thin layer of material is added to one or both sides of a core of homopolymer polypropylene. This material must heat-seal at temperatures below that at which the homopolymer will shrink. Historically, this was achieved by coating polymers such as polyvinylidene chloride (PVdC) onto pre-made film, but nowadays this technique is only used where some additional property is required of the coating, e.g. an oxygen barrier from the PVdC.

Most heat-sealable OPP is now produced by a coextrusion process whereby thin layers of sealant polymers are coextruded with the thicker central core, as shown in Figure 2.

Figure 2.
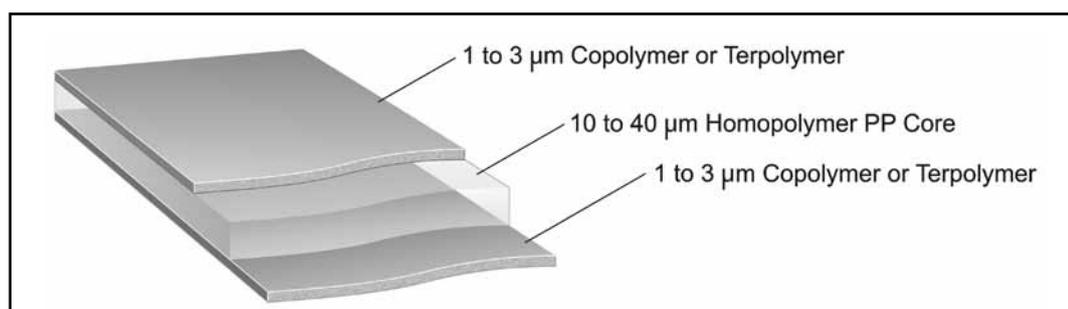
These sealant polymers are typically ethylene-propylene copolymers or ethylene-propylene-butene terpolymers, which seal at temperatures of 110–125°C or lower. Any shrinkage in these thin layers is resisted by the much thicker homopolymer which is thermally stable up to around 145°C.

With only a few microns of material that can flow during the sealing process, it is likely that there will remain channels through the seals where there have been folds or creases in the material, product contamination, or unevenness in the heat seal jaws. Hence the seals cannot be guaranteed completely airtight or watertight but they will be adequate to hold the product and prevent the moisture loss in the applications mentioned above.

Oriented polyester/ polyethylene laminate

The prevention of mould growth and other undesirable changes in blocks of hard cheese is often achieved by packing in a vacuum or in a modified atmosphere of CO_2 or CO_2/N_2 mix. In the MAP case, the acidification caused by CO_2 impregnation of the food has a preservative effect; residual CO_2 left in the headspace readily escapes the pack and results in a "pseudo-vacuum". Horizontal form-fill-seal machines are often used for this. The key design requirements for the packaging material are:

- Moderate *moisture barrier* to prevent the cheese drying out. Around 10 g/m²/day is adequate. Note that some drying out of the cheese is often desirable as the reduced water activity helps in preventing spoilage. Thus, too good a moisture barrier can be counter-productive, or must be balanced by improved hygiene.

- *Gas barrier* to limit oxygen entering the pack. The precise requirement will depend on cheese type, gas mixture used and shelf life required. In some cases, an OTR of around 100 cc/m²/day/bar is low enough; in others, a value nearer 10 cc/m²/day/bar is needed. The water activity of the cheese is decisive here. Sliced or grated cheese would also be more sensitive.

- *Hermetic seals* to prevent gas exchange and stop micro-organisms entering the pack. The fold pattern of the end seals, potential creasing of the material, and the possibility of seal contamination by crumbs of cheese (as illustrated in Figure 3) pose particular challenges for the packaging machine and material. The sealant needs to be able to flow into any channels to close them up and to flow around or through any contamination. To achieve this flow, the sealant must be present in sufficient quantity and it must be heated and pressure applied for long enough for the gaps to be filled.

Figure 3.
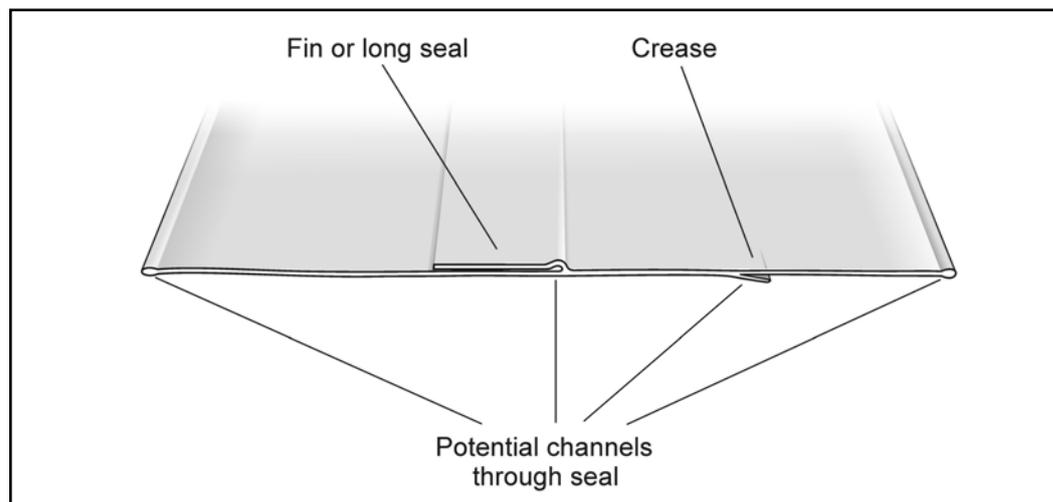
- Appropriate *slip levels* on the inside and outside of the material, adequate tensile strength and the shortest possible seal dwell time are other factors contributing to efficient packaging machine operation.

- Depending on the marketing strategy, the *appearance* requirements for these packs vary widely, from the plain transparent pack with a label for basic information, to fully printed creations with perhaps matt/gloss effects or a simulated paper look.

The following structure is often used to satisfy the above requirements:

> 12 µm OPET
>
> Ink
>
> Adhesive
>
> 40–70 µm "PE"

The inside layer, a film of 40–70 µm "PE" (e.g. LDPE, LLDPE or a PE-based copolymer) gives the moisture barrier required and the use of slip additives can give it the necessary coefficient of friction (CoF) for good machineability. Grades are available that start to seal at 100–120°C and possess the flow properties needed for hermetic seals. However, on their own, they would thin and weaken at the seal edge and stick to the heat seal jaws.

The oriented polyester is dimensionally stable to more than 200°C and so protects the sealant from the heated sealing jaws. It is available in thin gauges; at 12 µm, it will minimise its contribution to channelling when the material is folded but still will have sufficient tensile strength, both for the packaging machine and to act as a base for the printing process (if required). A 12 µm film will also have some gas barrier properties. Its OTR of 110 cc/m^2/day/bar could be low enough to give the pack the required shelf life.

If this barrier level is not sufficient, OPET is an excellent base onto which to coat a thin layer of barrier material such as:

- *Silicon oxide* or *aluminium oxide* applied to the inner side of the OPET by vacuum coating. This can reduce the OTR to around 1 cc/m^2/day/bar. These coatings have the advantage of being transparent.

- *Aluminium* applied by vacuum metallisation. This would give a similar OTR but the pack will be opaque (metallic); it would force any print to be on the surface of the pack, probably requiring an overlacquer to protect the ink – an additional cost.

- *PVdC copolymer* applied by coating and drying an aqueous dispersion. This is transparent; the OTR will be reduced to around 5–10 cc/m^2/day/bar.

Other ways of increasing the gas barrier of this structure include:

- The use of an OPA film, typically 15 µm thick, in place of the OPET. It would improve the OTR to about 30 cc/m^2/day/bar but has less dimensional and thermal stability.

- Inclusion of a barrier layer, such as EVOH, into the "PE" sealing layer by means of coextrusion.

It is necessary to bond the OPET film firmly to the PE-based sealant so that the resulting structure acts as a whole. This is normally achieved by means of a dry bond adhesive, either solvent-based, water-based or 100% solids. See the chapter on Methods of Production for more details.

Beverage carton

The use of cartons to pack liquids such as milk and fruit juices is well established. Extended shelf life of six or more months can be achieved by the aseptic packing of UHT products. The key requirements for such a pack are:

- High quality, leak proof seals.

- Barrier to gases to prevent oxygen ingress, as well as barrier to prevent flavour loss.

- Light barrier, to prevent light-induced off-flavours as well as accelerated oxidation, is needed for some products.

- Rigidity, so that the pack can stand on shelf and be easily handled by the consumer.
- Easy opening and reclosure of the pack.

Typical structures that satisfy these requirements are:

Structure A (from outside to inside)		Structure B (from outside to inside)	
15 g/m²	PE	2–3 g/m²	Ink
2–3 g/m²	Ink	15 g/m²	PE
230–400 g/m²	Board	230–400 g/m²	Board
10–30 g/m²	PE	10–30 g/m²	PE
6–9 µm	Aluminium foil	6–9 µm	Aluminium foil
2–8 g/m²	Tie polymer or primer	2–8 g/m²	Tie polymer or primer
30–60 g/m²	PE	30–60 g/m²	PE

The outer layer of PE protects the board from moisture. In some cases, the method of manufacturing the pack requires the outside of the pack to seal to the inside. This coating allows a PE-to-PE seal.

The board is primarily used to give structural rigidity for display and handling. It is the cheapest way of achieving this. The challenge of making leak-proof seals is similar to that faced for the cheese pack – except made worse by the presence of the board whose rigidity and thickness will tend to increase the size of potential channels in the seals. Furthermore, if heated seal jaws were used, the board would act as an insulator between them and the sealant.

As with the cheese pack, PE is still the material of choice for making the seal. To overcome the insulation issue, hot air may be used to soften the PE, while the very heat resistant board maintains the material structure. Alternative sealing techniques, such as ultrasonic or induction sealing, may also be used. In the latter case, the aluminium foil plays a dual role. Firstly, it absorbs the electromagnetic energy, heating the PE to the point at which it will seal. Secondly, it provides the effective barrier to gases and light that is needed for long shelf life products.

Extrusion coating is the most cost-effective way to apply both the outer coating and the sealant layers of PE. For the latter, good adhesion to the aluminium foil can be obtained by the use of a coextruded tie layer, e.g. an acid copolymer that will bond to both aluminium and PE. Such bonds must resist attack by substances in the food (e.g. fats, oils, aroma compounds such as limonene, and acids) that may migrate through the PE. Alternatively, a coating of primer can be applied to the foil from solution or dispersion prior to application of the PE.

Tandem extrusion coating and laminating techniques allow the whole structure to be produced in one operation, excluding the printing. Firstly, a laminating station uses extruded PE to bond the aluminium to the board. A tie layer or primer is not needed because the strength of the paper fibres is the limiting factor for bond strength and the aluminium protects the bond from chemical attack. Secondly, extrusion coating stations apply the PE sealant and outside coating.

In Structure A, the board is printed prior to the coating and laminating operation. In Structure B, the laminate is made first and then printed.

Not all requirements can be met through using multilayers. At the moment, the most effective easy open and reclose systems still rely on adding separate components, such as caps and spouts, to the main body of the pack.

Multilayer bottle

Many consumers have struggled to pour the correct amount of viscous sauces, like tomato ketchup or mayonnaise, when they have been packed in glass bottles. A "squeezy" plastic bottle offers increased convenience. However, many such sauce products are susceptible to oxidation, causing discolouration and off-flavours. So, the design requirements may be summarised as:

- A level of rigidity that allows the bottle to be squeezed.
- Resistance to "flex cracking", potentially caused by repeated squeezing of the bottle in the presence of fats and acids in the food product.
- Barrier to moisture to prevent product drying out.
- Barrier to oxygen to maintain product quality.
- Reclosure system to allow multiple use in the home.
- Transparency to allow the contents to be seen, as with glass.

These requirements are met by a bottle with the structure shown in Figure 4:

Figure 4.

Polyester   Polyester
Ethylene vinyl
alcohol
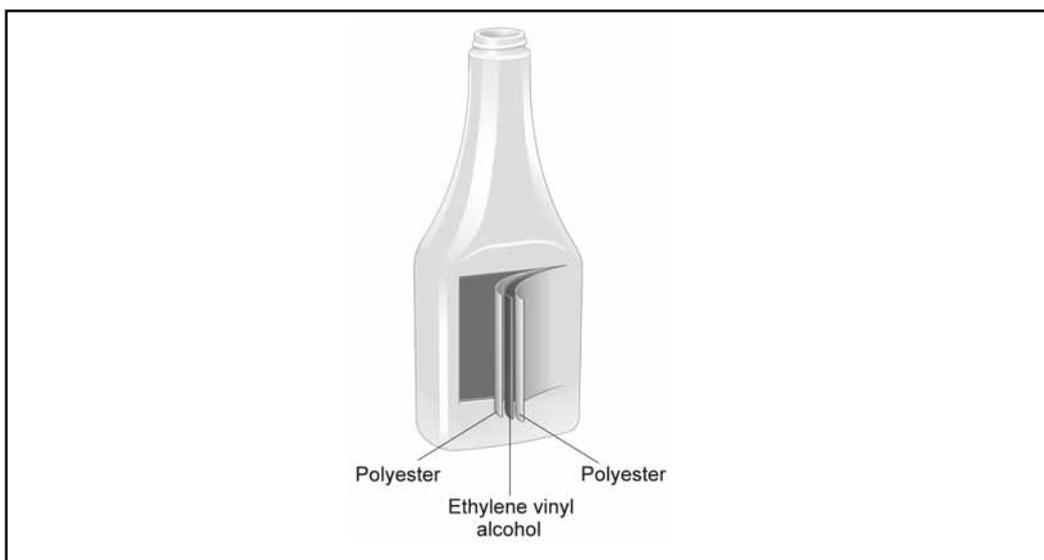
PET provides the necessary balance of rigidity and flexibility with the required chemical resistance and adequate moisture barrier. However, its oxygen barrier is inadequate to prevent spoilage of the product. This is provided by a layer of EVOH. Polyamide or oxygen scavengers could also be used. The bottle shape is made by coextrusion blow moulding or co-injection stretch blow moulding.

A separate, "snap open" closure is often used to give the consumer easy access. This could be a point for oxygen to enter the pack. To prevent this, at least within the retail distribution chain, an impermeable membrane is sealed across the mouth of the bottle, to be removed by the consumer before use. Such a membrane could be made of:

- Polyester – for strength and heat resistance.
- Aluminium foil – for barrier.
- Peelable polymer blend – to achieve a hermetic seal to the PET, preventing loss of product and ingress of oxygen, yet with a sufficiently weak peel strength to allow easy removal by the consumer.

Protecting the properties of materials

Some materials with excellent barrier properties are, nevertheless, relatively fragile. During the normal handling of the pack, the barrier would be rapidly degraded unless protected by other, more robust materials. In the beverage carton example, the PE on either side of the thin aluminium foil helps to cushion it against mechanical damage and consequent cracking and pinholes, which would otherwise reduce its effectiveness.

As mentioned earlier, the gas barrier properties of a polar polymer such as EVOH are reduced if it absorbs too much moisture. Such an effect can be minimised by sandwiching it between two layers of moisture-resistant polymer such as PE.

Metallised films have a very thin layer (40–100 nm) of soft aluminium deposited on their surface, which gives them their barrier properties. However, this thin layer can be easily scratched and damaged, with a consequent increase in permeability. "Burying" the metallised layer within a laminate protects it from mechanical damage and preserves its barrier.

Enhancement of barrier properties

In some cases, laminating thin barrier layers of aluminium or oxides can have an effect that goes beyond their protection. A thin layer of, say, silicon oxide would be absolutely impermeable were it not for discontinuities in the coating, creating microscopic channels or pinholes. The process of permeation through an impermeable layer with pinholes, as opposed to diffusion through a homogeneous layer, is such that the barrier properties of the oxide-coated film are noticeably improved by contact with a neighbouring layer. Although polyurethane-based adhesives intrinsically possess quite good gas barrier properties, a typical 3 g/m^2 application weight will by itself not add much to the overall barrier of the laminate. However, the continuous coating of adhesive will, in effect, seal up any holes in the oxide coating, thus creating a synergy whereby the barrier of the laminate is better than that of the base-coated film.

METHODS OF PRODUCTION

There are many ways of combining different materials to form packaging structures. This chapter will mention the most important and give some detail on four of them.

Coextrusion

In this process, two or more different plastic granules are heated and melted separately. The melts are brought together either before or at the die lips so that the combined plastics are extruded as a single product – a multilayer web of plastic film or sheet.

The two methods for extruding multilayer films are cast extrusion and blown extrusion. As an example, a cast or flat die coextrusion line is illustrated in Figure 5.

Figure 5.
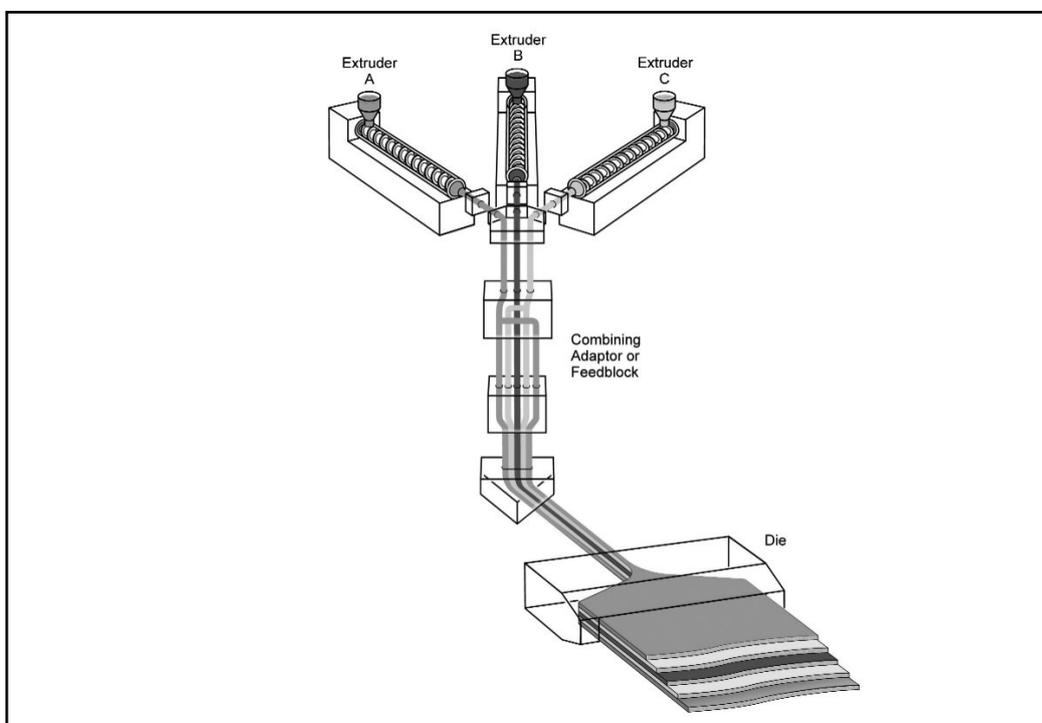
In this case, there are three extruders processing plastic granules A, B and C to produce a film or sheet with the structure ABCBA. For example, A could be LDPE, B a tie layer, and C EVOH. In the example shown, melts A and B are first split (so they can each form two separate layers) and then brought together with melt C in a combining adaptor or feedblock. The geometry of the feedblock can usually be adapted to reflect the desired relative layer thicknesses. The multilayer melt is fed into the die, whose "coat-hanger" design spreads the melt flow to the full width of the die lips. The rheological properties of the resins are chosen so as to maintain laminar flow and an even layer thickness during this stage. The web is cooled in a controlled manner on one or more chill rolls, as shown in Figure 6.

Figure 6.
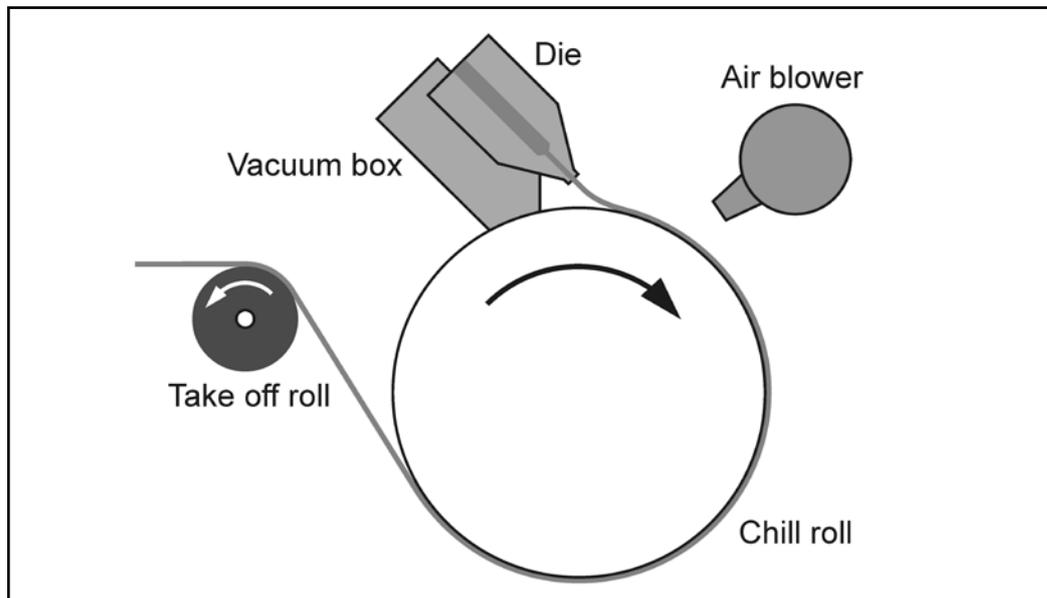
The thickness is controlled at a number of points:

1. The speed and hence the output of the extruders. Their relative outputs control the relative layer thicknesses.

2. The speed of the chill roll. The faster it turns, the more it draws down and thins the web as it emerges from the die lips.

3. The profile of the web. The thickness variation in the transverse direction is controlled by the separation of the die lips.

In the so called "stenter" or "tenter" production of oriented film (e.g. OPP), which can be seen as an add-on process to the cast coextrusion line, the initial coextrusion is a sheet of 1–2 mm thick. At carefully controlled temperatures, the sheet is heated and then stretched by a factor of 4–6 times in the machine direction by a series of rolls turning increasingly rapidly. Two endless chains of grippers then clasp the film on both edges. While continuing to move in the machine direction, and continuing to control the web temperature, the distance between the two sets of grippers is increased so as to stretch the sheet in the transverse direction, generally by a factor of 8–10. Thus, a 1.35 mm thick sheet may be reduced to a 30 μm film. After controlled cooling to anneal the film, the edges are trimmed and the film wound up.

In the alternative coextrusion technique of blown film extrusion, two or more resins are extruded through an annular die, with the melts being brought together just before the die lips. The melt coming out of the die is pulled upwards several meters high and fed through a nip formed by two rollers. The nip closes the system off so that air pressure can be applied on the inside to blow the material up in a giant bubble. At the same time, the bubble is air-cooled on the outside and, in some cases, from within. The film thickness is controlled by the blow-up ratio, i.e. the width of the bubble compared to the die diameter. The bubble collapses at the nip and is further processed in the same way as a mono-film, i.e. it is sliced open and the two halves separated and wound up into two reels of film.

Films with up to ten or more layers can be made by the blown extrusion technique. Since the resins stay separate until just before the die lips, it is less crucial to match the rheology of the resins than in the cast process. In this respect, it is a more flexible process. However, the geometry of the complex and expensive coextrusion dies is fixed, so they must be designed with a limited range of layer thickness ratios in mind. There are limitations on how much these ratios can be varied. As a trade-off, a blown extrusion line can cover more reel widths than a cast extrusion line.

Next to the fundamental choice of film thickness and width, there are several important parameters governing the choice between cast and blown film extrusion, including:

- Polymer type: PA, PET and PP are traditionally better suited for cast extrusion; PE is typically better suited for blown extrusion.

- Thickness of film: Very thick (above ca. 200 µm) or very thin (below ca. 30 µm) films are difficult to produce on a blown film line.

- The two processes can result in different degrees of crystallinity, degree and direction of orientation, gloss, transparency etc.

Co-injection stretch blow moulding

This process is used to make the PET/barrier material/PET bottle mentioned earlier (see Figure 4). Injection stretch blow moulding is a two-stage process in which a preform is first made by injection moulding. The preform has the shape of a test-tube with a neck moulded with a finished thread. In the second stage, the thread of the preform is held while the body is first heated by infrared radiation and then placed in a blow mould. It is simultaneously stretched using a stretch rod inserted through the neck and blown into the final shape by compressed air. The blow mould is cooled to freeze the material in the correct shape.

At the injection moulding stage, there are different technologies for the co-injection of different polymers:

- *Sequential injection*: PET is first injected into the mould, followed immediately after by the barrier resin and then again by more PET. Following this manufacture of the three-layer preform, the subsequent blowing step proceeds in the normal way as described above.

- *Simultaneous injection*: PET and the barrier resin are injected together, and the barrier material is directed to the middle of the preform. Following this manufacture of the three-layer preform, the subsequent blowing step proceeds in the normal way as described above.

Lamination

Coextrusion can only combine two or more plastics, starting with them as resins (granules or pellets). To combine two or more materials in web form, possibly including non-plastics, a lamination process is required. This section describes some different lamination processes.

Extrusion lamination

As illustrated in Figure 7, a curtain of molten polymer, e.g. LDPE, is extruded from a flat die, similar to that used in the casting process, onto the primary web of material. At the same time, the secondary web is fed in from the other side. The three layers are pressed against a chilled drum by an impression roll. The molten polymer solidifies, bonding the two webs together. After trimming of the edges, the laminate is wound.

Figure 7.
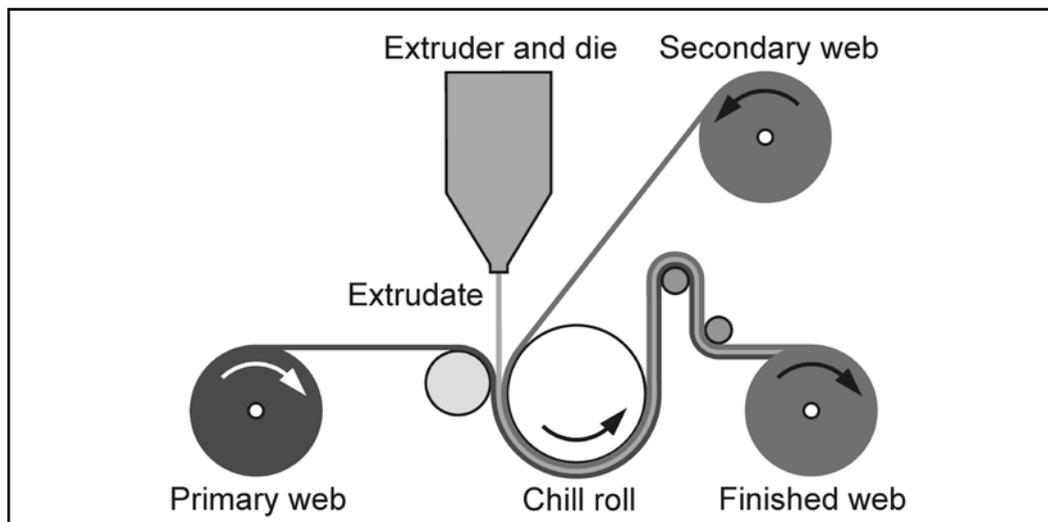
As with the cast film process, the variation of thickness of the extrudate across the web is controlled by die bolts and feedback from a thickness measuring device. Overall thickness is a function of the speed and output of the extruder balanced against the overall line speed. Polymer can be extruded at 10 µm or less at line speeds up to 600 m/min or more. The bonding of the extrudate to the webs depends on:

- *Chemical compatibility* of the polymer and the webs: This can be improved by:
  – Corona discharge treatment of a web to increase the surface tension.
  – Coating the web with a chemical primer.
  – Coextruding the polymer, using a thin surface layer of copolymer with chemical groups that promote bonding (typically acid copolymers).

- *Line speed*: Bonding becomes more difficult at higher line speeds, mainly because adhesion requires a certain degree of oxidation of the polymer surface. The less time it takes for the polymer curtain to travel from the die lips to the nip, the less oxidation and the worse the bond.

- The *temperature* of the polymer also affects the degree of oxidation. In addition, the hotter the polymer when it enters the nip, the better it will flow and adhere to the webs. On the other hand, relatively high temperatures (~300°C) are needed to achieve these effects, so care is needed in polymer selection and processing conditions to minimise cross-linking or thermal breakdown and generation of off-odours.

- The *thickness* of the extrudate: The thicker the extrudate, the more it retains its heat on its travel to the nip. This helps the bonding process.

Due to the relative ease of bonding PE to paper fibres, extrusion lamination is particularly suited to paper- and board-based structures.

The need for a careful balancing of the process conditions means that extrusion laminating is best suited for long runs of standard structures.

Adhesive lamination

For shorter runs and for plastic-film-based structures (including laminates with aluminium), adhesive lamination is often used. Different techniques are available; "dry bond lamination" is described to illustrate the process and is shown in Figure 8.

A coating of solvent- or water-based adhesive is applied to the primary web. The coated web is passed through an oven where hot air is blown onto the web to dry off the solvent or water and raise its temperature.

Figure 8.
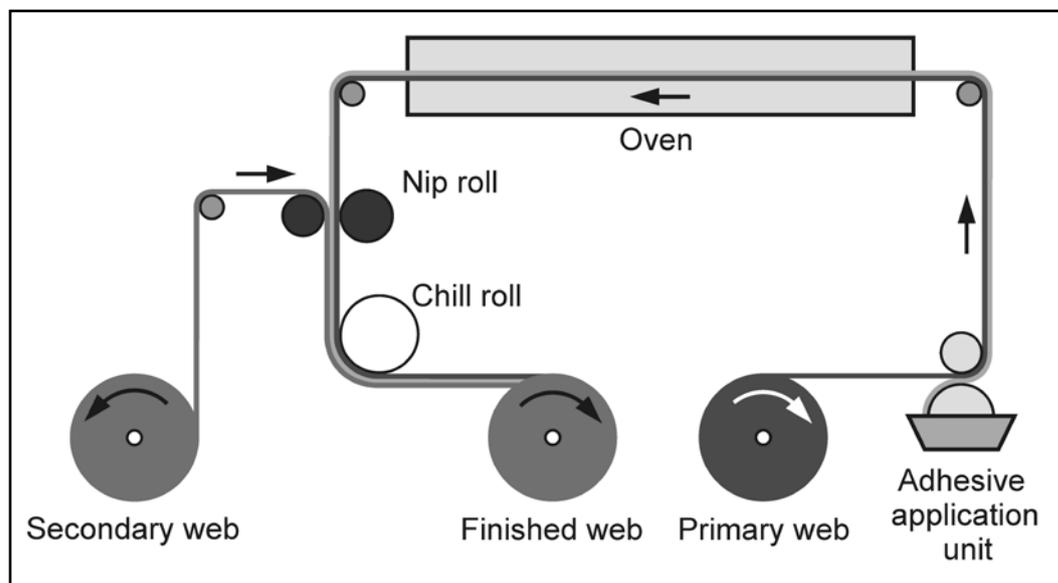
At the exit of the oven, the adhesive is warm and tacky, but "dry" because the solvent was removed – hence the name "dry bond lamination". A heated nip roll is used to bond it to the secondary web. The resultant laminate is cooled on a chill roll to increase the adhesive viscosity and hence the immediate bonding (called "green tack"), and then wound under pressure to minimise the chance of the webs separating.

For non-reactive adhesives, this is the end of the process, although there will usually be some improvement in the bond as the finished roll cools further. For stronger bonds, reactive adhesives are used and, for these, a subsequent curing period is an essential part of the process. While in the roll, cross-linking reactions take place to increase the molecular weight of the adhesive and increase both the bond strength and the resistance of the laminate to temperature and chemicals. This takes from one day to two or more weeks, depending on the precise chemistry employed. The reaction proceeds more quickly at higher temperature, so laminates may be cured in "hot rooms", e.g. at 40°C, to reduce the time. Details on this chemistry are given in the next chapter.

The primary web has the longer journey through the machine and is heated, so it is usual to choose the more heat-resistant, less-extensible material for this role. The more heat-sensitive, stretchable materials, such as LDPE, will be the secondary web.

The quality of the bond depends on a number of factors:

- *Adhesive selection,* both in terms of the chemical compatibility with the webs to be laminated, and in terms of the conditions to which the laminate will be exposed, e.g. elevated temperatures or chemically aggressive foodstuffs.

- Some webs, e.g. polyolefins, need *corona discharge or other treatment* to give a surface energy that will allow the adhesive to "wet out" (spread evenly) properly.

- *Adhesive dry weight* should be around 2.5–6 g/m^2; in general, the more uneven the surface of the web, the more is needed.

- Correct *machine conditions* that minimise residual solvents and ensure sufficient heat transfer at the nip.

In general, adhesive lamination is quicker to set up and not so difficult to control as extrusion lamination so it is better suited to shorter runs and the use of a greater variety of webs. It is also more suitable to in-line printing or coating operations.

Solventless lamination is similar to dry bond lamination except that the adhesive used is 100% solids so there is no drying process. The adhesive is generally heated to reduce the viscosity and then applied to the primary web by a roller system. It is immediately nipped to the secondary web, cooled and wound up. The initial green bond will be relatively weak but all solventless systems are reactive and cure to give stronger bonds. One-component systems rely on reacting with moisture from the webs or atmosphere. Two-component systems are mixed just before application and react with each other. The advantages of the solventless method include lower capital and running costs, no solvent emissions to be dealt with and the use of lower adhesive weights (below 2 g/m^2). Disadvantages include a need for tighter control of process conditions and less ability to deliver very high bond strengths and resistance to high temperatures and chemicals.

For "wet bond lamination", one of the webs must be paper-based. A water-based adhesive, such as a starch or protein dispersion, is applied to one web and the other web is immediately nipped in. The laminate can then be passed through an oven and the water dried off by passing through the permeable paper. Alternatively, and especially when thicker grades are used, e.g. board, the substrate simply absorbs the water and dries the adhesive to form a bond.

Wax and hot melt lamination

A layer of molten wax or hot melt is applied between two webs and then cooled to bond them together. The method of application depends on the viscosity of the laminant and includes roller systems, gravure and slot dies. The wax remains heat-sensitive and hence such techniques are ideally suited to pack types where the material is folded or glued rather than heat sealed.

Coating

A number of coating techniques are used to produce multilayers.

Extrusion coating is essentially extrusion lamination without nipping in a secondary web. The extrudate is simply applied onto a single web. This results in a two-layer as opposed to a three-layer structure. The most common example is paper/PE or board/PE.

Solvent based coatings are applied to webs by techniques similar to those used for adhesive lamination and the process is illustrated in Figure 9. Again, the solvent is driven off in an oven; by raising the web temperature sufficiently, reactive coating systems can also be cured during this time.

Figure 9.
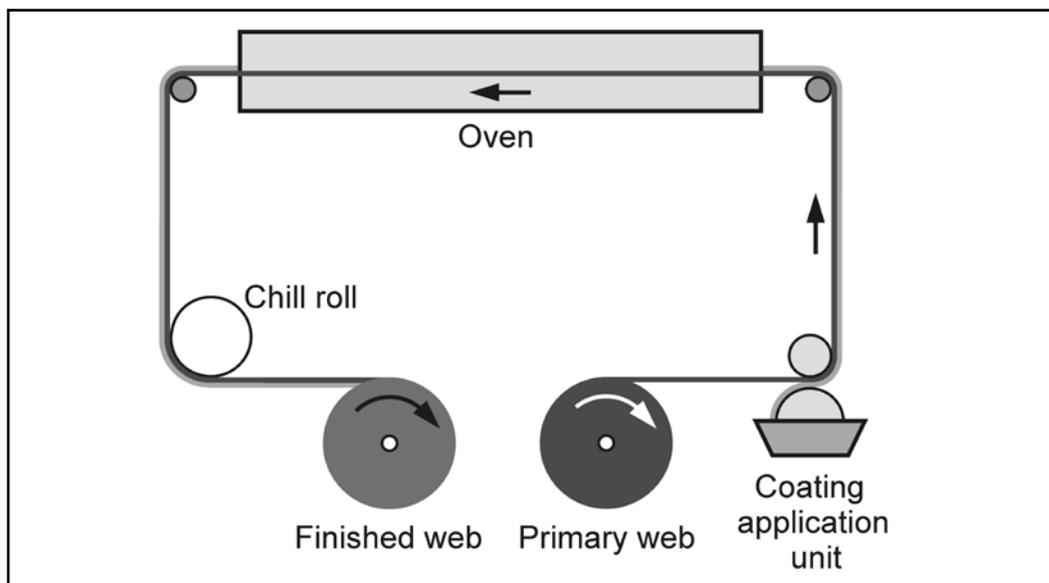
Aqueous dispersions are also applied as coatings in this way. For aqueous coatings, heating techniques such as infrared and ultrasonics can be used, as well as hot air.

Wax and hot melt coatings can be applied using the same techniques as for lamination.

Although the above coating techniques are similar to those used for lamination, *vacuum coating* is fundamentally different. The principle is to evaporate a source material in a high vacuum and deposit the vapour onto a moving web. Aluminium is the most commonly used source. The resultant metallised films have a metallic appearance and provide a light, moisture and gas barrier. Silicon oxide and aluminium oxide are also used and result in transparent films. A common technique for heating aluminium is to use electrically heated ceramic "boats" into which wires of aluminium are fed. Another technique, as used for silicon oxide, is to fire a beam of electrons onto a solid source. In all techniques, the aim is to produce a uniform density of vapour across the whole width of the web.

Figure 10.
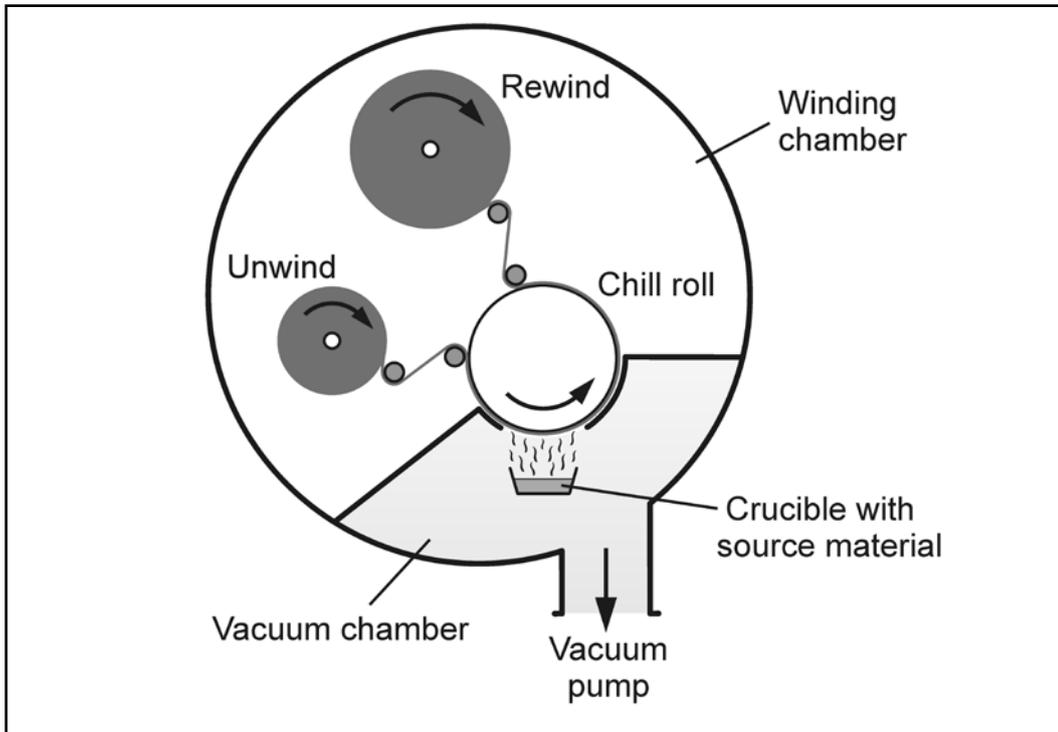
Figure 10 shows how the base web is unwound from a reel and held on a cooled cylinder during its exposure to the vapour, which condenses to form a solid coating. Typical coating thicknesses are in the range of 40–100 nm. The coated material is then rewound. Vacuum coating is a batch process only capable of handling one reel of material at a time. When the reel has been run, the chamber needs to be returned to atmospheric pressure, the coated roll unloaded, a new target roll loaded and the chamber pumped down to the required vacuum again. Therefore, thin films, such as 12 μm OPET or 15 or 20 μm OPP, are the most commonly used substrates.

CHEMISTRY

Previous reports in the *ILSI Europe Report Series* have covered the chemistry of most of the materials used to make multilayer structures. Adhesives and coatings are an exception to this.

Adhesives

Many types of adhesives can be used in laminates but by far the most important for food packaging are two-component systems based on reactive polyurethane chemistry. This chemistry is based on the reaction of an isocyanate with a hydroxyl group to form a urethane linkage:

$$R^1-N=C=O \ + \ R^2\text{-}O-H \ \longrightarrow \ R^1-N-C-O-R^2$$

urethane linkage
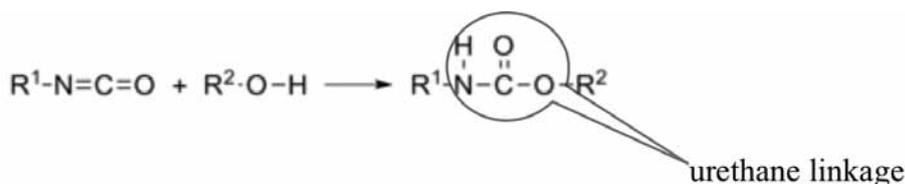
One component of the adhesive will be a pre-polymer, which has been made by reacting a diisocyanate with polyester or polyether polyols. The pre-polymer will possess two or more free isocyanate groups. Common starting diisocyanates include:

- Aromatic diisocyanates
  - TDI   Toluene diisocyanate
  - MDI   Methylene diphenyl diisocyanate

- Aliphatic diisocyanates
  - IPDI   Isophorone diisocyanate
  - HDI   Hexamethylene diisocyanate

The other component will be a diol or polyol, possessing two or more –OH groups. When the components of the adhesive are mixed, chain lengthening and cross-linking occur through reaction of these –OH groups with the isocyanate groups on the pre-polymer:

$$OCN–R^1–NCO + HO–R^2–OH$$
diisocyanate + diol
$$\downarrow$$
$$\ldots –O–CO– NH–R^1–NH–CO–O–R^2–O–CO– NH–R^1–NH–CO–O– \ldots$$
polyurethane
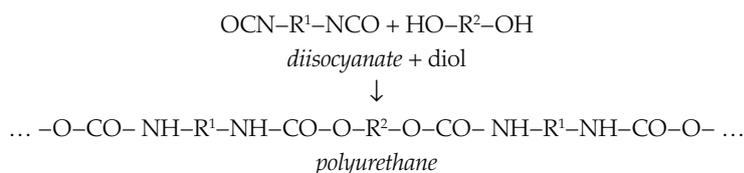
A number of other reactions can take place, the most important of which are:

a. Because water has an –OH group, it can also react with an isocyanate:
$$R–NCO + H_2O \rightarrow R–NH_2 + CO_2$$
isocyanate + water → primary amine + carbon dioxide

b. The amine formed can then react further with an isocyanate group to form a urea linkage:
$$R–NH_2 + R–NCO \rightarrow R–NH–CO–NH–R$$
amine + isocyanate → substituted urea

c. There can be further reactions between an isocyanate and already-formed urethane and urea linkages. These also produce side chains and cross-linking.

Of most concern to food safety is the fact that the isocyanate pre-polymer will always contain a proportion of free diisocyanate monomer. Normally, this will be entirely consumed within the adhesive layer during the curing reaction, either by reacting with the polyol or by means of reactions (a) to (c) above. However, if the laminate is used to pack a food before the cure is complete, the diisocyanate can migrate through the sealant layer into the food. Here it will react with water to form an amine. In the food, water is in excess and reaction (b) will not take place. Thus, amines could be permanently formed in the food (before possibly reacting

away, especially with any alcohol or fat content in the food). If aromatic isocyanates have been used as a starting material, these will be primary aromatic amines (PAA), some of which are potential carcinogens. Hence, it is important to ensure that a full cure of the adhesive takes place before packing food.

Coatings

A wide variety of coating is used in multilayers to give specific functional properties. Many are applied from aqueous dispersions, which are dried and coalesced to form a thin film as described in the previous chapter. Others may be dissolved in an organic solvent. In the past, toluene was widely used but this has now been replaced by safer, less odorous compounds such as methyl ethyl ketone (MEK), ethyl acetate and ethanol. The most commonly used coatings are listed below. There is an extensive use of proprietary blends of different chemical components in order to achieve the required functional properties; hence, the chemical descriptions are inevitably somewhat simplified.

Protective coatings

Primarily used to protect surfaces from mechanical damage, these can also give gloss and heat resistance and protect from chemical corrosion. There are three main systems:

*   *Non-curing systems* include those based on nitrocellulose (NC) resin.

*   *Heat set* systems use high temperatures in the drying tunnel of the coating machine to bring about thermoset reactions. For example, epoxy resins prepared from epichlorohydrin and bifunctional phenols may be cured with phenolic, amino or anhydride resins – or by combinations of these.

*   Systems that *cure at ambient temperatures* include those based on reactive polyurethane systems similar to those described above for adhesives.

Heatseal coatings

These usually use polymers and copolymers of vinyl acetate, vinyl chloride, styrene and modified polyolefins, such as ethylene acrylic acid (EAA) and ethylene vinyl acetate (EVA). Blends are frequently used to ensure good bonding, both onto the substrate, e.g. aluminium foil, and a different material to which it will be sealed, e.g. a polystyrene-based pot. Blending may also be used to achieve peelable seals. Polyester-based systems are increasingly being used in some applications to give a chlorine-free option.

Primers

These are used to improve the bond between a substrate and an otherwise incompatible coating. Polyethyleneimines are widely used but there are also other systems, for example, EAA dispersions or reactive polyethyleneamines being used to prime aluminium foil for PE extrusion coating.

Multifunctional coatings

PVdC coatings, which are based on copolymers of vinylidene chloride with either vinyl chloride or alkyl acrylates, can be tailored to the required properties of gloss, heat sealability and barrier to moisture, gases and odours or flavours. Aqueous dispersions of polymers and copolymers based on acrylic and methacrylic acid are used to make acrylic coatings, which provide similar functionality but with much less good barrier.

Coldseal coatings

Aqueous dispersions containing blends of acrylic resins with natural rubber latex are used to make coatings that can be sealed self-to-self using just pressure, with no heat. Synthetic rubber is used for a small proportion of formulations.

Release lacquers

Polyamide-based release coatings are applied to the opposite surface to prevent such coldseals sticking ("blocking") when wound under pressure in the reel.

More detailed descriptions of typical coatings can be found in Annex IV of "Code of Practice for coated articles where the food contact layer is a coating" pp 38–52 (CEPE, 2009).

MIGRATION OF SUBSTANCES FROM MULTILAYERS

The components of multilayers may contain chemical substances that have a potential to migrate into the packed food. Such substances could include:

- Residues of starting substances used to make a material, e.g. monomers.

- Additives used to achieve specific technical effects, e.g. anti-oxidants, slip agents.

- Non-intentionally added substances (NIAS), e.g. impurities in raw materials, reaction by-products.

To ensure the safety of consumers of the packed food, it is essential to control the amount of such migration. Subsequent chapters deal with legislative requirements and the evaluation of the safety of a material in contact with food. This chapter summarises the factors that affect migration levels.

Starting with the simple model of a monolayer plastic containing a potential migrant that is placed in contact with a food, the following factors must be considered:

- The initial concentration of the migrant in the polymer.

- The ratio of the surface area of the plastic to the mass of the food. The greater this is, the quicker the substance will be transferred.

- The diffusion coefficient, which describes the rate at which the substance can move through the plastic to be available for transfer into the food.

- This diffusion coefficient is itself dependent on temperature. The higher the temperature, the quicker the substance will move.

- The time that the plastic is in contact with the food.

- The partition coefficient is defined as the ratio of the migrant concentration in the packaging to its concentration in the food at equilibrium. It measures the relative affinity of the polymer and the food for the substance. For example, a polar substance will partition between a polar and a non-polar medium so that there is a higher concentration in the former.

- The thickness of the plastic, combined with the ratio of surface area to weight of food, gives the mass ratio of plastic to food. The higher the mass, the higher the concentration of the substance in the food at equilibrium.

The first four factors influence the rate of migration, with the concentration of the migrant in the food increasing with time until it is limited by the last two factors at equilibrium.

Because testing actual foods for the presence of migrants from packaging is both technically demanding and costly, an understanding of these factors has allowed the development of methods that use food simulants rather than actual foods. The principle behind these tests is that they should be more severe than using the actual food and conditions of contact. A detailed discussion of the principles behind such tests and how they relate to what happens in actual food packages can be found in a review by Franz and Stoermer (2008).

An increased understanding of the theoretical basis for migration has led to the development of migration models. There are two goals for such models: first, to provide worst-case estimates to replace physical testing of specific combinations of packaging and food or food simulants; and second, in conjunction with statistical data on food consumption and packaging use, to provide probabilistic estimates of overall exposure.

The basic principles governing the migration from single webs into foods also apply to all plastic multilayer materials but the complexity increases. The rate and amount of migration from one layer to another (which starts as soon as the multilayer is manufactured) must also be considered. In consequence:

- A migrant in the food contact layer might move not only into the food but also into other outside layers, thereby reducing the concentration in the layer and, hence, the eventual equilibrium concentration in the food.

- Conversely, a migrant in an outer layer might move into the food contact layer and, from there, into the food. There will be a time lag in such behaviour, which might be significant depending on the delay between the manufacture of the multilayer and its use to pack the food.

In a multilayer structure of the type layer A/layer B/layer C, and where layer C is in contact with the food, it is possible that layer B forms a barrier to migrants from layer A entering layer C. The Plastics Regulation (EU) No 10/2011 defines layer B as a "functional barrier" if it reduces the level of migration of a substance from layer A to layer C to a level where it can meet regulatory limits. Note that this is a pragmatic definition. It does not necessarily require zero migration. Also, a material that provides a functional barrier to a specific migrant at a specific concentration in a specific layer A for a given temperature and time will not necessarily act as a functional barrier if any of these factors are changed.

Besides migration from layer A to layer C, substances from layer A can also enter layer C by another mechanism called "chemical set-off". When multilayers are wound on reels or sheets are stacked, layer A comes into direct contact with layer C whereby substances can be transferred without any visible transfer. Important factors for this transfer are:

- The level of the substance in layer A.

- The time and temperature of storage of the reels or stack before use.

- The relative affinity of the substance for layer A and layer C, i.e. the partition coefficient.

- The inter-layer pressure within the reel or stack.

Even though most of the work on migration has focussed on polymer-based packaging, some other types of materials (e.g. inks, adhesives and coatings) might reasonably be expected to behave as quasi-plastics, while others might not. Some differences include:

- The models for diffusion assume macroscopic homogeneity of polymers. Papers and boards are non-homogenous aggregations of fibres.

- The models assume no loss of migrant, e.g. through reaction with the polymer. Paper and board can absorb some substances thus making them unavailable for migration.

- The barrier properties of materials like aluminium foil and metallised films are strongly dependent on their physical continuity. Their permeability depends on the number and size of pinholes, scratches etc., which are themselves dependent on manufacturing methods and how the materials have been handled rather than on their diffusion and partition coefficients.

- For laminated and coated multilayers, the interface between the layers might not be homogenous. For example, there might be microscopic air bubbles entrapped between layers, which form a barrier to migration.

- For reactive adhesives and coatings, the reactants might be potential migrants. The amount that transfers into a food contact layer will therefore depend on the kinetics of the reaction as well as the migration factors.

The potential transfer of substances from multimaterial multilayers into food is therefore a much more complex issue than that for plastic monolayers. It is not sufficient only to consider the food contact layer. There is the possibility of transfer from the rest of the structure. What acts as a functional barrier in one circumstance cannot be assumed to do so in another. The possibility of transfer in the reel or stack from the outside of a material to the food contact layer must always be considered.

REGULATORY ASPECTS WITHIN THE EUROPEAN UNION

General requirements

Multilayer materials, like all food contact materials and articles, are subject to Regulation (EC) No 1935/2004 on materials and articles intended to come into contact with food, often referred to as the Framework Regulation. The key provisions of this legislation are:

- The *general safety requirement* that food contact materials "shall be manufactured in compliance with good manufacturing practice so that, under normal or foreseeable conditions of use, they do not transfer their constituents to food in quantities which could endanger human health or bring about an unacceptable change in the composition of the food or bring about a deterioration in the organoleptic characteristics thereof" (Article 3).

- The *traceability* of materials "… shall be ensured at all stages …".

- Provision for *specific measures* for groups of materials or the substances used in making them.

- Basic rules for *active and intelligent materials.*

- Procedures for the *authorisation* of substances including a safety assessment by the European Food Safety Authority (EFSA).

- *Labelling* requirements.

- The principle of a written *Declaration of Compliance* (DoC) confirming that materials which are covered by specific measures do, indeed, comply with all the rules.

A further measure, Regulation (EC) No. 2023/2006, lays down the rules on good manufacturing practice (GMP) for food contact materials. This aims to clarify what are "good manufacturing practices" as referred to in Art. 3 of the Framework Regulation, and deals only with those aspects of GMP strictly related to food contact compliance. It sets out general requirements for quality assurance systems, quality control systems and places special emphasis on documentation. It currently has two annexes giving more specific GMP requirements for printing inks and for plastics recycling processes.

Plastics legislation

Of the "specific measures" that have so far been adopted, those for plastics are the most important for multilayer materials. The Plastics Directive, 2002/72/EC, and its subsequent amendments, together with Directives on vinyl chloride monomer, on migration testing and on food simulants, was replaced as from 1 May 2011 by a new regulation, the Commission Regulation (EU) No 10/2011 on plastic materials and articles intended to come into contact with food. It came into effect on 1 May 2011, although there is a two-year transition period during which existing materials may continue to comply with 2002/72/EC. It applies to plastics multilayers (even when coated or printed) and to the plastic components of multimaterial multilayers. To summarise the main provisions:

- The plastics layers may only be manufactured from substances (monomers, other starting substances and additives) that are contained in the "*Union list*" of authorised substances (Annex I of the Regulation). For substances other than additives and monomers, e.g. polymer production aids, requirements at national level may exist. Additives for which a valid application for EU authorisation has been received before 1 January 2007 that are on the "*provisional list*" (http://ec.europa.eu/food/food/chemicalsafety/foodcontact/documents_en.htm) can continue to be used, pending a decision on their inclusion in Annex I. Substances present in the material (even unintentionally) that have not been officially reviewed need to undergo a risk assessment by the manufacturer. This assessment may include exposure considerations.

- Some substances are subject to *specific migration limits* (SML) and must not transfer to the food in amounts exceeding this limit.

- The total transfer of constituents of plastics to food should not exceed 10 mg/dm² – this is the *overall migration limit* (OML).

- There are *rules for assessing compliance* with the above limits. Food simulants (test media) and testing conditions (time and temperature) are given for the testing of materials. It is important to note that there are some changes to the testing regime compared to Directives 85/572/EEC (as amended by 2007/19/EC) and 82/711/EEC (as amended by 93/8/EEC and 97/48/EC). For this reason there is a transition period of five years for the new testing regime to be fully implemented.

- When screening such materials, the Regulation allows for *migration modelling* and other strategies to replace actual testing for specific migration.

- Plastic layers that are separated from the food by a *functional barrier* may be manufactured from unlisted monomers and additives provided that:
  - They are not classified as CMR (*carcinogenic, mutagenic or toxic to reproduction*).
  - The limit on *vinyl chloride monomer* is respected.
  - They are not in *nanoform*.
  - In addition, for all plastics multilayers only, the migration of unlisted substances is *not detectable* with a detection limit of 0.01 mg/kg.

- *Inks, coatings and adhesives* in plastic multilayers may be made from unlisted substances. However, if they contain any listed substances that are subject to an SML, the suppliers have to supply adequate information on them to enable the manufacturer of the finished material to ensure compliance.

- Plastics in *multimaterial* multilayers must comply with the compositional requirements but the migration limits do not apply for these structures (except the limit on vinyl chloride monomer).

- A *written declaration* that the material complies with the rules shall be made available to the customer. Supporting documentation must be kept, and made available to the authorities on request. The content of this Declaration of Compliance (DoC) is specified in some detail in Annex IV to the Regulation.

It is intended that there will be an official EU Guidance Document to the Plastics Regulation, which will help industry and competent authorities to understand and implement these provisions. It should include definitions, explanations on Articles of the Regulation, more information on the migration testing regime and, in the context of the DoC, details on the information flow in the supply chain.

Other measures

In addition to some measures dealing with individual materials or substances, e.g. Directive 2007/42/EC on regenerated cellulose film, and Regulation (EC) No 1895/2005 on epoxy derivatives, there are two further regulations of particular relevance to multilayer packaging for food.

Regulation (EC) No 282/2008 concerns *recycled plastics* used to manufacture materials and articles intended for food contact. When produced by mechanical recycling processes, they shall only be obtained from food contact grade plastics recycled using processes authorised in the EU following a safety assessment performed by EFSA. It also states that the recycling process shall be managed by an appropriate quality assurance system. The Regulation sets out the conditions under which a process can be authorised and provides for a Community Register of authorised processes and for Member State auditing. The DoC for a material containing recycled plastics must state that it was made by an authorised process and quote the relevant Register number. Labelling of the recycled plastic article itself is voluntary. Until the first list of EU authorised recycling processes is adopted, national legislation is applicable. It is anticipated this will take a few more years. Note that, if the recycled plastic can be demonstrated to be used behind a functional barrier or if it has been obtained by chemical recycling, this Regulation does not apply.

Regulation (EC) No 450/2009 deals with *active and intelligent* packaging in contact with food. It states that only substances that are in a "Community list" of authorised substances (not yet published) can be used as the active or intelligent components of such packaging. However, there are exceptions:

• Substances that are *intended to be released* to the food are subject to specific provisions given in the Framework Regulation and to food legislation.

• Substances that are *separated from the food by a functional barrier* can be used. As with the Plastics Regulation, substances classified as CMR or in nanoform are excluded.

As a first for substances authorised for food contact materials, active or intelligent substances are required to be "suitable and effective for the intended purpose of use". When the active or intelligent article could conceivably be mistaken for a food ingredient (e.g. a sachet containing powder), labelling is required to give an adequate warning to the consumer.

SAFETY EVALUATION

*I*n this context, "safety" means the safety of the consumer, arising from any possible interaction between food and multilayer food packaging. As has been seen in the previous chapter, this lies at the heart of the Framework Regulation with its requirement that materials "… do not transfer their constituents to food in quantities which could endanger human health …".

To evaluate the safety of a structure one must consider the intrinsic hazard of a substance, including potential impurities and the consumer's exposure to the substance, which together allow one to carry out a risk assessment:

- The *hazard* of a substance, conventionally characterised by toxicological studies that ideally allow a tolerable daily intake (TDI) or acceptable daily intake (ADI) to be derived. The TDI/ADI is obtained from the "no observed adverse effect level" (NOAEL) divided by a safety factor of 100 or more.

- The *exposure* of the consumer to the substance, i.e. the amount of that substance ingested through the diet over his/her lifetime. This depends on:
  - The quantity of the substance in the packaging material.
  - The extent to which the substance transfers from the material into the food – as described in the chapter on Migration of Substances from Multilayers.
  - The fraction of foods in the diet for which this packaging material is used.
  - The ratio of the pack surface area to food weight.
  - The amount of food consumed.

In the EU, EFSA is responsible for the risk assessment of component substances used to make plastic materials and articles. There are some deviations from the ideal risk assessment scenario as outlined above. Specifically:

- Data requirements in the petitioning process depend on the migration level, with cut-off levels at 50 ppb, 5 ppm and 60 ppm. For migration below 50 ppb three mutagenicity tests should be performed. Above 50 ppb, at least a 90-day oral toxicity study should be included. When the migration is below 50 ppb, EFSA will not receive a full dataset and consequently will not be able to define an ADI, but considers an intake below 50 ppb not to be a health risk when mutagenic properties are excluded.

- Reliable information on material use is not generally available, compromising the exposure assessment. Reduced datasets can also lead to restrictions on the materials (and sometimes foods) for which the substance is allowed to be used.

In summary, EFSA's proposal for a specific restriction on a substance is not always a measure of its intrinsic hazard properties, and does not incorporate a refined exposure assessment. Furthermore, the EU Commission's risk management approach is, with some exceptions, based on a standard consumption of 1 kg of packed food per consumer of 60 kg body weight per day and a standard pack area-to-food weight ratio of 6 dm² material per kg food. This results in the equation: SML = TDI × 60 kg body weight. In exceptional cases, where significant exposure routes other than food packaging exist (e.g. background exposure), the regulator may decide to allocate only part of the TDI to exposure from food contact materials.

With the safety factors involved, and the overestimation of exposure, the SML is in many cases a compliance limit rather than a safety limit. Nevertheless, compliance with the plastics legislation remains an important tool with which the packaging manufacturer and food packer can demonstrate the safety of all plastic multilayers and of the plastic components of multimaterial multilayers.

The above procedure – EFSA evaluation followed by European Commission authorisation – only applies to monomers and additives used in plastics for food contact. However, other substances are present in plastics, e.g. aids to polymerisation, processing aids, solvents, and reaction or degradation products. Additionally, a wide range of non-plastic components are used in multilayer materials (such as coatings, inks, adhesives and paper) in which other substances may be used. For all of these the safety according to Article 3 of the Framework Regulation remains to be demonstrated. Manufacturers are obliged to carry out their own safety assessment according to the above principles, using internationally recognised scientific methods including exposure considerations. In practice, this only needs to be done where alternative assessments such as the following examples are not available:

- Impurities and reaction/decomposition products of EU-regulated substances are included in EFSA's safety assessment of those substances and need not be repeated.

- EFSA (or its predecessor the SCF) have evaluated a number of substances used in non-plastics. Although not currently listed in EU legislation, those evaluations remain a reference point for the substances' hazard properties.

- For the use of evaluated substances in non-plastics, the manufacturer can combine the official hazard assessment with use and exposure information obtained from other sources.

- An authorisation in the EU as direct food additive or flavouring is seen as sufficient demonstration of safety. Care must be taken to ensure that this additional use does not completely change consumer exposure to the substance. Also, the impurity profile needs to match that of the food grade substance, or needs to be assessed separately.

- Certain materials or substances have been authorised by the national legislation of an EU Member State. For example, a paper being used in a multilayer could comply with the German Federal Institute for Risk Assessment Recommendation XXXVI (BfR, 2009), or an adhesive could comply with Recommendation XXVIII (BfR, 2010). A list of national legislation is available at the European Commission's website (http://ec.europa.eu/food/food/chemicalsafety/foodcontact/documents_en.htm). Such compliance can be quoted to demonstrate the safety of a substance or material, but manufacturers must be careful to observe the specified conditions of use and any additional testing needed. With the principle of mutual recognition, compliance with the national regulations of an EU Member State has the advantage that, if the material has been legally marketed in that country, it should also be legal to market it in other EU countries.

- For substances or materials not regulated in the EU or its Member States, the manufacturer can refer to the authorisation in a non-EU state if based on internationally accepted risk assessment methods. Notably, the US Food and Drug Administration (FDA) Regulations are often referred to. Thus, an adhesive manufacturer might seek to demonstrate safety by quoting compliance with FDA section 21 CFR 175.105 (FDA, 2009). Again, specified conditions of use and any additional testing must be observed.

- The Council of Europe has published Resolutions on some substances and materials that are not yet covered by specific EU legislation. The relevance of inventory lists not based on a safety assessment is minimal, and furthermore the Resolutions have no legal status. Two Resolutions which, nonetheless, have proven their value are AP(89) 1 on colourants in plastics and AP(92) 2 on aids to polymerisation (Council of Europe, 2004a, b).

Manufacturers of semi-finished components and of finished multilayer packaging materials face a particular challenge to make sense of all the information coming from different raw material suppliers. In the end, they are responsible for arriving at a well-founded conclusion on safety and legal compliance for their products. Increasingly, industry sector associations issue detailed guidelines on safety evaluation and compliance assessment for their members. Some examples relevant for multilayer packaging include:

- The coatings industry's "Code of practice for coated articles where the food contact layer is a coating" (CEPE, 2009).

- The paper manufacturers'"Industry Guideline for the compliance of paper & board materials and articles for food contact" (CEPI, 2008).
- The printing inks sector's "Guideline on printing inks applied to the non-food contact surface of food packaging materials and articles" (EuPIA, 2009).
- Flexible Packaging Europe's "Code for good manufacturing practices for flexible and fibre-based packaging for food" (FPE, 2011).

Communication along the supply chain is essential. A vital tool in this process is the DoC, which enables the downstream user to investigate compliance. Equally, the upstream supplier also has certain information needs for their safety assessment. Ideally, the following information should be exchanged:

- *Up the supply chain*: The type of food to be packed, the target consumer, the food storage conditions, and the in-pack processing conditions carried out by both packer and consumer (e.g. pasteurisation, sterilisation, microwave reheating of the pack).
- *Down the supply chain*: The identity of any migratable substances in the components of the structure that are subject to a restriction, their concentrations and/or the results of migration tests, modelling analysis, and any worst-case calculations.

For multimaterial multilayers, manufacturers of the final structure need to combine compliance aspects from various types of components used. For structures incorporating plastics, compositional compliance with the Plastics Regulation is required for plastic layers in multimaterial multilayers. It is most often convenient – even if not a legal requirement – to stick to the regulatory provisions even when a functional barrier layer is present, and to subject the finished structure or the food contact layer to migration testing when that food contact layer is a plastic. Often, they may be able to make a logical argument for the safety and compliance of a structure by quoting satisfactory results on analogous structures in a "product family" or by using a "building block" approach with the results of tests and assessments on individual components.

An important point is that, when a chemical reaction takes place during the conversion process (e.g. adhesive curing), it is the converter that is controlling that reaction. The possible chemical reactions must be understood and the production processing conditions controlled. This is seen most clearly in the use of isocyanate-based polyurethane adhesives, with their capability to generate PAAs in foods if not fully cured. A "non-detectable" PAA test on one batch of laminate cannot imply the safety of other batches unless it can also be shown that they are produced under identical or better conditions, including the time and temperature of cure.

The final step in the process is the food packer's check of the compliance information received, i.e. a verification of the conditions of use of the multilayer packaging material in relation to their actual food packaging application, and a clearance on the organoleptic influence of the packaging on the food.

ENVIRONMENTAL ASPECTS

Like all packaging, multilayer materials must comply with Directive 94/62/EC on Packaging and Packaging Waste (and its amendments) which establishes three "Essential Requirements". In summary, packaging should be made so as to:

1. Prevent packaging waste by minimising the package weight and volume to that which is adequate for safety, hygiene and acceptance of the packed product.

2. Permit its re-use or recovery, including material recycling, energy recovery, composting or biodegradation and to minimise its impact on the environment when it is disposed of.

3. Minimise the impact on the environment of any noxious and other hazardous constituents (heavy metals and eco-toxic substances) when it is incinerated or landfilled.

Earlier, it was shown how thin layers of different materials can be combined to fulfil design requirements that would otherwise be very difficult to achieve. For example, product collation and preservation might be achieved by a monolayer plastic if it were very thick, but it would undoubtedly fail on the requirements of machineability, convenience and cost. Multilayers play a key role in minimising the weight and volume of packaging.

Re-use of multilayer packaging is mostly out of the question, for several reasons including hygiene and logistics. However, the issue of recovery is more complex. It is undoubtedly more difficult to recycle a multilayer than a single material, because the individual components must first be separated. But, it can be done and is being done; for example, in 2008 the beverage carton industry recycled some 13 billion containers. This equates to 350,000 tonnes or 33% of the market for these containers (ACE, 2009). Paper fibre is re-used in paper and board products, aluminium as metal powder or as aluminium trioxide for use in cement, and PE is incinerated for energy. To achieve this, systems for collection and sorting of the containers have had to be put in place, as well as the recycling facilities themselves.

Beverage cartons are a high-volume product and are relatively large in size. They are also fairly standardized in composition. This facilitates the collection and sorting process. There are viable recycling processes for other multilayer structures such as the other examples listed in this document. The problem is the cost, in both financial and energy terms, of getting the used pack from the consumer to the recycling plant. Smaller volumes per pack type, and a more diverse composition, are other disadvantages. As the waste collection infrastructure develops, more multilayer packaging materials will be recycled, but progress is likely to be slow and there will remain many structures for which material recycling is not an option.

It is expected that biodegradable and compostable materials will start to play a bigger role as technical performance develops. A driving force is the fact that packaging waste from traditional plastics remains very visible in the environment because it degrades so slowly. But, from an environmental impact point of view, waste food is still much more of a problem than packaging waste and there are life cycle assessment implications to be considered on the consequences of the loss of resources due to degradation and on the implications of degradable materials being diverted to landfill.

On the other hand, almost all multilayer packaging contains well over 50% organic materials and so meets the requirements of EN 13431:2004 on energy recovery. This is currently the disposal method of choice for most structures.

No discussion on environmental aspects can be complete without looking at the wider context of sustainability. A study by ESU-services Ltd for Flexible Packaging Europe (Büsser and Jungbluth, 2009), using Life Cycle Analysis techniques, has shown that multilayer packaging has a minor environmental

impact compared with other factors such as the production of food and the way in which it is stored and used. The study looked at ground and instant coffee packed in polyester/aluminium foil/PE laminates and butter packed in aluminium foil/wax/paper laminate. The results of the study were calculated for eight environmental indicators using the CML 2001 method (Guinée, 2002). They showed that, for all indicators, the impact of the packaging was minor compared with that of coffee or butter production, the brewing of the coffee, and the transport and storage of the butter.

For small pack sizes, the relative contribution of the packaging is greater. For coffee, the extra impact of producing and packaging the single portion pack is more than off-set by a significant reduction in the energy needed for preparation of the coffee. When including the typical fraction of the brewed coffee not consumed but going to waste, the energy balance tips even more in favour of the single portion pack. For the butter example, the argument is that, in certain scenarios such as catering and hotels (where such small packs are predominantly used), the extra impact of the packaging is also more than offset by the reduction in food waste.

The above study highlights the importance, when looking at sustainability and life cycle analysis, to take the entire product lifecycle into consideration rather than looking at the packaging in isolation.

GENERAL CONCLUSIONS

*F*ood packaging can require a variety of performance characteristics such as strength, rigidity and barrier to light, moisture and gases. In many cases, a single material cannot provide all the required properties and it is most cost effective to achieve them by combining thin layers of different materials into a single multilayer packaging structure. Materials used include paper, metal and plastics such as polyethylene, polypropylene, polyester and polyamide, together with ancillary components such as inks, coatings and adhesives. Lamination, coating and coextrusion techniques are commonly used production techniques.

The consumer safety of such packaging is determined firstly by the safety of the mono-material components and secondly by the techniques used to combine them. As with all packaging for food, multilayer materials must comply with Regulation (EC) No 1935/2004. However, they are not always covered by specific measures, and manufacturers may have to look to a variety of different regulations and codes of practice in order to demonstrate the safety and compliance of their products.

Multilayer packaging materials are also formulated to have minimal impact on the environment after their packaging function has ended. The separation of such layers for recycling presents a challenge that can currently be met only for some high volume products such as beverage cartons. Even where such recycling is not possible, energy recovery, minimisation of source materials and reductions in food waste can make a multilayer an environmentally effective option.

ANNEX: FURTHER EXAMPLES OF MULTILAYER STRUCTURES

Retorted fruit cup

Fruit, e.g. pineapple, is sealed into a cup that is retorted to give an extended shelf life under ambient conditions. The cup is a coextruded sheet, which is thermoformed to the required shape. The lid is an adhesive laminate. Key requirements are:

• Hermetic, yet peelable seals for easy opening by the consumer.

• Good oxygen barrier and some moisture barrier.

• Resistance to the retort conditions.

• Rigidity of cup.

The following example structures meet these requirements:

Lidding (from outside to inside)		
12 µm	OPET	Thermal resistance for retort process and heat seal jaws
40–100 nm	Silicon oxide	Transparent oxygen and moisture barrier
3–5 g/m²	Adhesive	Bonding and synergistic improvement of SiOx barrier
15 µm	OPA	Strength and tear resistance to aid peeling of lid
3–5 g/m²	Adhesive	Bonding
40–50 µm	Polyolefin-based sealant	Hermetic peelable seal
Cup (from outside to inside)		
	Polypropylene	Rigidity, thermal resistance for retort process, moisture barrier
	Tie layer	Bonding
	EVOH	Oxygen barrier
	Tie layer	Bonding
	Polypropylene	Rigidity, thermal resistance for retort process, sealability to lid, moisture protection of EVOH

Breakfast cereal liner

A common pack for ready-to-eat breakfast cereals is a plastic bag within a paperboard carton. The latter provides rigidity for handling and transport. The main requirements for the inner bag are:

• Efficient operation of vertical form-fill-seal machines fitted with constant heat jaws, able to withstand the drop of up to 750 g of cereal on the hot seal.

• Seals that are adequate to hold the product, yet peelable by the consumer.

• Good barrier to moisture to keep the cereal crisp.

• Some degree of dead-fold for reclosing of the opened liner bag.

These properties can be provided by:

25–60 µm	HDPE	Moisture barrier and temperature resistance relative to the sealant layer
5–10 µm	Polymer blend	Controlled bond between the HDPE and ionomer, which allows a "burst" peel mechanism
5–10 µm	Ionomer-based blend	Low temperature sealing (differential temperature compared with the HDPE) and excellent hot tack to withstand the weight of product dropping on hot seal

Biscuit rollwrap

Round biscuits are often packed in a roll. The material is wrapped around the biscuit stack and sealed, inside to inside, along the length of the stack. Often, the resultant seal is then tacked down onto the pack body to make it lie flat. The end seals are folded and sealed flat against the end biscuits. For this operation, inside to inside, inside to outside, and outside to outside sealing are all needed. To keep its freshness, the biscuit requires protection from moisture ingress.

The following structure is widely used:

3–5 g/m²	PVdC coating	Provides gloss and print protection, sealability, good release from heat sealing jaws and correct slip characteristics
	Ink	
35–40 μm	Cavitated OPP	Gives the basic strength of the pack, heat resistance and contributes to the moisture barrier. It is cavitated to provide a degree of dead-fold, a suitable background for the printed design, and a low weight-to-thickness/stiffness ratio
2–3 g/m²	PVdC coating	Provides additional moisture barrier and sealability

Crisp packet

Potato crisps are packed at high speed on vertical form-fill-seal machines fitted with constant heat sealing jaws. For reasons of economy and machine efficiency, the vertical or back seal is generally of the lap type, that is, sealing the outside of the material to the inside. Key requirements are:

• Barrier to moisture in both material and seals.

• Barrier to light which can initiate oxidation reactions.

• Inside to inside and inside to outside sealing.

• In some cases, gas flushing is used to remove oxygen from the packs and improve product quality and/or shelf life. In this case, gas barrier is required in the material and an improved quality of seals.

• Easy opening by the consumer.

Bags made from the following two-ply laminate meet these requirements (outside to inside):

15–20 μm	Coextruded OPP film, made up of:	
1–2 μm	Co- or terpolymer PP	Low temperature sealing to inside layer
12–17 μm	Homopolymer PP	Strength and heat resistance
1–2 μm	Co- or terpolymer PP	Surface to be printed
	Ink	Visible from the outside through the clear OPP film, which moreover protects the ink from abrasion
1.5–2.5 g/m²	Adhesive	Bonding, usually 100% solids for economic reasons
40–100 nm	Aluminium metallisation	Light and moisture barrier and some degree of gas barrier. Note that this thin layer is protected from mechanical damage by being sandwiched between the two OPPs
15–20 μm	Coextruded OPP film, made up of:	
1–2 μm	Co- or terpolymer	Surface for aluminium deposition
12–17 μm	Homopolymer PP	Strength and heat resistance
1–2 μm	Co- or terpolymer	Low temperature sealing to itself and outside layer

Ground roast coffee pack

For prolonged shelf life, coffee is either gas flushed or vacuum packed to give an oxygen-free environment. The prime requirements for the packaging are good oxygen and light barriers and excellent, leak-free seals. In some packs, the seals are peelable for easy opening. For vacuum packaging of roast coffee beans, a good puncture resistance is needed.

One widely used structure is:

12 µm	OPET	Thermal resistance for the heat seal jaws and mechanical strength for the printing operation and packaging machine
	Ink	Printed design
2.5–4 g/m²	Adhesive	Bonding
7–9 µm	Aluminium foil	Barrier to O_2 and light
2.5–4 g/m²	Adhesive	Bonding
40–70 µm	PE-based sealant	Hermetic peelable seal

Yoghurt pot lidding

Yoghurt packed in polystyrene cups can be lidded with reel-fed material or with pre-cut lids, depending on the packaging machine. In the latter case, handling requires that the lids must be flat, rigid and easily separable from each other. In all cases, they should be easily peelable by the consumer, while giving liquid-tight seals. A moderate oxygen and moisture barrier is required for fresh products, a greater barrier is needed for long-life products. Three solutions are common:

Pre-cut lids based on aluminium foil		
	Ink	
30–40 µm	Embossed aluminium foil	Thermal resistance for the heat seal jaws, flatness and rigidity. Excellent barrier
3–10 g/m²	Lacquer	Peelable heat seal
Pre-cut lids based on polyester film		
	Ink	
50 µm	Embossed OPET	Thermal resistance for the heat seal jaws, flatness and rigidity. Some barrier
3–10 g/m²	Lacquer	Peelable heat seal
Laminate option for reel-fed lidding		
	Ink	
40–50 g/m²	Paper	Print base, strength to resist tearing on opening
2.5–4 g/m²	Adhesive	Bonding
	Metallisation	Barrier and appearance
12 µm	OPET	Substrate for the metallisation; provides strength to resist tearing on opening. Some barrier properties
3–8 g/m²	Lacquer	Peelable heat seal

LIST OF ACRONYMS

ACE	The Alliance for Beverage Cartons and the Environment
BfR	Bundesinstitut für Risikobewertung – the German Federal Institute for Risk Assessment
BOPP	Biaxially oriented polypropylene – often abbreviated to OPP (q.v.)
CED	Cumulative energy demand
CML	Institute of Environmental Sciences, University of Leiden
CMR	Carcinogenic, mutagenic or toxic to reproduction
CoF	Coefficient of friction – the ratio of the tangential force required to produce sliding divided by the normal force between the surfaces
DoC	Declaration of Compliance (in the context of food contact legislation)
EAA	Ethylene acrylic acid
EFSA	European Food Safety Authority
EVOH	Ethylene vinyl alcohol
FDA	Food and Drug Administration (of the United States of America)
GMP	Good manufacturing practice
HDI	Hexamethylene diisocyanate
HDPE	High-density polyethylene
HFFS	Horizontal form-fill-seal machine – typically used to pack solid products
IPDI	Isophorone diisocyanate
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
MAP	Modified atmosphere packaging – packing a food in a defined gas mixture to inhibit microbial activity and hence food spoilage
MDI	Methylene diphenyl diisocyanate
Met. OPP	Metallised oriented polypropylene
Met. OPET	Metallised oriented polyethylene terephthalate (polyester)
NIAS	Non-intentionally added substance
OML	Overall migration limit
OPA	Oriented polyamide
OPET	Oriented polyethylene terephthalate (polyester)
OPP	Oriented polypropylene – often used as an abbreviation for BOPP (q.v.)
OTR	Oxygen transmission rate – a measure of the permeability of a material to oxygen. Used as a measure of barrier, the lower the figure, the better the barrier.
PAA	Primary aromatic amine
PPA	Polymerisation production aid (a subtype of processing aids).
ppb	Parts per billion (normally by weight, µg/kg)
ppm	Parts per million (normally by weight, mg/kg)
PE	Polyethylene
PET	Polyethylene terephthalate (polyester), short for PETP.
PP	Polypropylene
PVdC	Polyvinylidene chloride
RH	Relative humidity
SCF	Scientific Committee on Food – the risk assessment group organised by the EU Commission prior to the establishment of EFSA
SiOx	Silicon oxide, an inorganic barrier coating material
SML	Specific migration limit (mg/kg food)
TDI (1)	Tolerable daily intake – normally expressed as mg/kg body weight
TDI (2)	Toluene diisocyanate
WVTR	Water vapour transmission rate – a measure of the permeability of a material to moisture. Used as a measure of barrier, the lower the figure, the better the barrier.

GLOSSARY

Adhesive	Polymeric material applied by coating technology, with the primary function of bonding two webs together.
Aseptic packaging	Process whereby a sterile food, usually treated by UHT (q.v.), is packed in a sterile container under conditions that will maintain that sterility and hence extend shelf life.
Beta Gauge	Device that uses the absorption of β-particles to measure the thickness of a moving web.
Blown film	Plastic film produced on a blown extrusion line.
Cast film	Plastic film produced on a cast extrusion line.
Copolymer	Polymer formed by the polymerisation of two or more different monomers.
Corona discharge treatment	Exposure of a web to a plasma created in air at atmospheric pressure in order to modify the surface, making it more receptive to the application of coatings and promoting better bonding.
Dead-fold	Ability of a material to retain its shape when folded.
Die	Component of an extrusion machine that has a narrow slot through which the polymer is extruded to form a film or sheet. Cast extrusion uses a flat (straight) die, and blown extrusion an annular die.
Dry bond lamination	Lamination technique where a solution or dispersion of adhesive is applied to the primary web and then passed through an oven to remove the solvent or water. The secondary web is nipped into the dry, but tacky, adhesive.
Flex cracking	Crazing and cracking that can be induced in plastics under stress, e.g. by repeated flexing, and is often exacerbated by chemicals and/or temperature.
Functional barrier	Defined in the Plastics Regulation (EU) No 10/2011 as "a barrier consisting of one or more layers of any type of material which ensures that the final material or article complies with Article 3 of Regulation (EC) No 1935/2004 and with the provisions of this Regulation".
g/m²	Measure of the basis weight of a material. Generally used for papers, inks, adhesives and coatings.
Green bond or green tack	Bond strength of an adhesive before it is fully cured.
Homopolymer	Polymer formed by the polymerisation of a single monomer.
Infrared Gauge	Device that uses the absorption of infrared radiation to measure the thickness of a moving web.
Machine direction	Direction in which the web is moving through a machine.
Migrant	Chemical substance that has the potential to transfer from one layer of a multilayer structure into another, and from the food contact layer into the packed foodstuff.
Micron (μm)	Equal to micrometre. The conventional unit of measurement of thickness for aluminium foil and thin films. Often also abbreviated to μ.
Nanoform	No official definition available yet. Regulation (EC) No 450/2009 on active and intelligent packaging uses the phrase "substances deliberately engineered to particle size which exhibit functional physical and chemical properties that significantly differ from those at a larger scale"; this is a good working description.
Pre-polymer	Starting substance that is itself a polymer, but intended to undergo a further chemical reaction (usually a larger-scale polymerisation or crosslinking).
Primer	Coating that is applied onto a web with the purpose of improving the bonding or adhesion to a subsequent non-web layer (e.g. another coating).
Seal	Either the operation of sealing, usually by heat, or else the part of the package resulting from the heat-sealing operation.

Slip	Ability of a web to slide against itself or another surface, generally measured by the coefficient of friction or CoF (q.v.).
Solventless adhesive	Also known as 100% solids adhesive. Such adhesives have a sufficiently low viscosity to be applied to a web without reduction by solvent or water.
Stenter	Process for orienting film in the transverse direction whereby an endless chain of grippers clasp each edge of the web and separate, thus stretching it. Also sometimes known as "tenter".
Tenter	See "Stenter".
Terpolymer	Polymer formed by the polymerisation of three different monomers.
Tie layer	In a coextruded film, sheet or coating, a layer of polymer that acts as an adhesive for two other layers. For example, in the construction Polymer A/Polymer B/Polymer C, Polymer B is a tie layer that bonds Polymer A to Polymer C.
Transverse direction	Direction across the web, at right angles to the machine direction (q.v.).
UHT	Abbreviation for ultra-heat treatment or ultra-high temperature. A processing technique whereby a food is fully or partially sterilised by rapidly heating it to a high temperature, holding it there for a short time and then cooling it. For example, milk may be UHT-treated by heating to more than 135 ºC for 1–5 seconds. Usually used in combination with aseptic packaging (q.v.).
Web	Continuous sheet of film, foil or paper, generally wound onto reels.
Wet bond lamination	Lamination technique whereby a solution or dispersion of adhesive is applied to the primary web. The secondary web is immediately nipped in and the adhesive is dried either by absorption into the substrate or by permeation through the substrate.

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