tonnes in 2007, which is double the 1987 tonnage. Of this 18 million tonnes, 58% is used in rigid packaging (bottles, tubs, caps, etc.) and 42% in flexible applications, i.e. films and laminates. Not surprisingly, 70% of all plastics packaging is used for food and drink, the remainder being used for household chemicals, pharmaceuticals, cosmetics and toiletries, and a range of other non-food uses, plus industrial products such as shrink and stretch film, and carrier bags.

13.3 Key properties for packaging applications

Compared with other packaging materials, plastics are generally lighter in weight, more easily formed into different shapes, and extremely versatile. This versatility is largely responsible for their growth in usage: the ability to carefully tailor the performance of a plastic container to the needs of the product, the market and the demands of the supply chain means that there is a 'plastic' solution to almost all packaging problems.

When considering the performance of plastic materials, the properties of most interest in packaging applications, and their relevance in use, are summarised as follows.

Tensile strength and elongation are probably of most practical relevance in flexible packaging, especially during form, fill and seal machine operations. Films and laminates must withstand the tension of being pulled through a forming station without stretching or breaking, and bags/sacks must withstand the force of the product weight being dropped into place without distortion. For pallet stretch wrapping, a film with high elongation is required, the most commonly used material being linear low density polyethylene. Tensile strength is a directional property and specifications will state values in machine and cross direction.

Tear strength is also relevant in flexible packaging applications, both in terms of resistance to tearing during machine forming and subsequent handling. Tear properties also influence consumer convenience in ease of opening. In general, plastics have good resistance to tearing, compared, say, with paper, and if the consumer is expected to tear open a pack it is advisable to facilitate this by using a paper/film laminate and/or incorporating an easy-open device in the pack, such as a laser cut.

Impact strength is a measure of a material's resistance to breakage when subject to a sudden impact, such as a falling object. It is probably more meaningful to evaluate the impact strength of a filled plastic component, e.g. a drum or a sack using a series of drop tests, than to rely on data generated from impact tests on the plastic materials.

Surface friction influences the ease with which a packaging material or component will travel through the packaging line, such as a film moving over a forming collar. It also influences the stability of palletised loads during transit and of primary/secondary packs on display. Surface friction can be modified to the desired level by the use of additives during film manufacture.

Viscoelasticity or 'creep' is a major consideration when deciding which plastic to use for a given application. All thermoplastics exhibit some degree of permanent deformation under load. This typically manifests itself when filled containers are stacked on pallets during storage. Stacking tests under load, using actual packaging components, are essential to evaluate the true extent of a material's suitability.

Optical properties such as transparency and gloss mainly influence pack aesthetics. If the product has an attractive appearance and is stable on exposure to light, then a highly transparent pack may be desirable. Totally amorphous polymers are transparent; as the degree of crystallinity increases, transparency decreases and the materials become hazy and, eventually, opaque.

Chemical stability describes the extent to which a polymer is suitable for direct contact with a range of different product types, such as organic solvents, oils, acids or alkalis. Table 13.3 provides guidance on the general suitability of the common packaging plastics with a selection of such products, although this must be verified in each specific case, preferably using actual packaging components and products.

Environmental stress cracking is the failure of a plastic component under the combined effects of stress and an aggressive environment. Stress in plastic mouldings will bring about mechanical failure over time, but the presence of stress cracking agents such as detergents and oils can dramatically accelerate this failure, sometimes with catastrophic results.

Moisture and gas barrier properties of plastics determine their suitability to provide the required shelf life of the product. The data shown in Table 13.4 may be used as a starting point in selecting which plastics may be suitable, but again, storage tests using actual packs and actual products are essential. Refer back to Chapter 3 for more detailed information on this.

Temperature data of plastics has been referred to in Chapter 12, which differentiates between the glass transition temperature (T_g) and the melting temperature (T_m). T_g is the point at which the material changes from a glassy to a rubbery state and it occurs in the amorphous regions of a polymer. T_m is the temperature at which the crystalline regions of a polymer melt and is therefore always higher than T_g. Totally amorphous polymers (e.g. atactic polystyrene with its large benzene ring on the main carbon chain) do not have a melting temperature and thermosets do not have a glass transition temperature (due to their high degree of crosslinking). The temperature information given in Sections 13.4 and 13.5 refers mainly to T_m (except for polystyrene) as this is of most practical importance when selecting which plastic to use for a given application, such as suitability for sterilisation, microwave or conventional oven cooking, and the material's heat sealability.

Heat sealability is an important property to consider for a range of flexible packaging such as sachets, bags, flow wraps and pharmaceutical blister packs, as well as semi-rigid packs such as thermoformed trays and pots. The temperature at which the sealing medium softens and starts to flow must be compatible with what can be achieved by a combination of sealing head temperature, pressure and dwell time on the packaging machine, so that correctly sealed packs are achieved. Pack seals must survive the rigours of the supply chain, i.e. they must maintain the containment, protection and preservation functions, and be openable by the final user.

Density, as shown in Table 13.5, is an important consideration for cost in use. Plastic resins are traded by weight and for applications such as flexible packaging it is the area of material which is of interest, i.e. the number of square metres of

Table 13.3 Chemical resistance of the common packaging plastics

Material	Dilute acid	Dilute alkali	Oils and greases	Aliphatic hydrocarbons	Aromatic hydrocarbons	Halogenated hydrocarbons	Alcohols
LDPE/LLDPE	****	****	** variable	*	*	*	****
HDPE	****	****	** variable	*	*	*	****
PP	****	****	** variable	*	*	*	****
PVC	****	****	*** variable	****	*	** variable	*** variable
PS	**	****	**	****	*	*	* variable
PET	****	**	****	****	**	**	****

**** Very good, *** Good, ** Moderate, * Poor.
Source: British Plastics Federation (www.bpf.co.uk).

Table 13.4 Moisture and oxygen barrier properties of the common packaging plastics

Material	MVTR	OTR
LDPE/LLDPE	15–25	7000–8000
HDPE	5–12	1500–2000
PP	3–7	1800–2500
PVC (U)	20–60	50–80
PS	70–160	4000–6000
PET	16–20	60–120

MVTR = moisture vapour transmission rate for 25 μ film in g/m^2/day; test conditions 38°C, 90% relative humidity.
OTR = oxygen transmission rate for 25 μ film in cm^3/m^2/day; test conditions 25°C, 50% relative humidity, 1 atmosphere.

Table 13.5 Density of the common packaging plastics

Material	Density kg/m^3
LDPE/LLDPE	910–930
HDPE	940–965
PP	880–920
PVC (U)	1230
PS	1070
PET	1360

Exact figures will vary with grade.

material available from 1 kg of resin. For any given thickness of film, this area can be calculated from the data in Table 13.5. It can be seen that material densities vary considerably and this must be taken into account, along with the price per tonne of resin, when comparing alternatives for a given end use.

13.4 The common packaging plastics

The ability to tailor material performance to requirements has already been emphasised as one of the most significant contributors to the growth in use of plastics in packaging and it is the case that most solutions are to be found amongst polyethylenes, polypropylene, polyvinyl chloride, polystyrene and polyethylene terephthalate (see Table 13.2). Even allowing for inaccuracies in data collection, it is clear that these materials dominate the packaging market. This section will review the key properties and uses of these common packaging plastics, while Section 13.5 will address the 'other' types of plastics used.

Note that it is not the objective of this chapter to provide fully comprehensive information on every packaging application of every plastic, which would be unrealistic within the space available. Several sources have been consulted in putting together this section (see Section 13.8) and some give quite extensive additional information. This section and Sections 13.5 and 13.6 aim to provide short notes on each material, sufficient to begin to make informed choices for given end uses, but the reader is required to explore other sources for more detailed information.

13.4.1 The polyethylene family of plastics

Ethene ($H_2C{=}CH_2$) is a gaseous by-product of the process of cracking of long chain hydrocarbons to produce much sought-after products such as petrol and aviation fuels. The development of polyethylene (original trade name Polythene) and its commercialisation in the 1940s/1950s have already been mentioned as an important milestone in the development of plastics for packaging.

For convenience, polyethylenes are usually classified according to density. The more branched chains in the structure, the less these chains can be packed together (i.e. there is more steric hindrance) and thus the lower the density of the material. As chain packing increases, so does tensile strength, barrier to moisture and gasses, heat resistance and opacity.

Low density polyethylene

Low density polyethylene is produced by a high pressure process, and has a mix of long and short branched chains and around 50–65% crystallinity, making it translucent in appearance. It is soft and flexible with good elongation before breakage and good puncture resistance. It has a fair moisture barrier and poor oxygen barrier and softens at around 100°C (lower for some grades), making it an economical polymer to process and readily heat sealable, but of course unsuitable for cook-in packs. In common with all the polyolefins, it is non-polar and must be surface treated prior to printing or laminating.

Linear low density polyethylene

Linear low density polyethylene is a copolymer of ethylene and other alkenes such as butene, hexene or octene. This results in an essentially linear chain arrangement, with the comonomer (i.e. the butene, hexene or octene) forming short, regular chains on the main carbon backbone. It has similar properties to LDPE although it is tougher with slightly better barrier properties. It requires slightly more energy to heat seal and its operating range for sealing is narrower than LDPE, making control of seal temperature on the packaging machine more critical. It is also a little more transparent than LDPE. As already stated, it has very high elongation before break, which accounts for its widespread use in pallet stretch film.

Around 70% of all LDPE and LLDPE is used as film. This includes secondary/tertiary packaging such as pallet stretch film, collation and pallet shrink film, as well as primary packaging such as sacks, retail carrier bags, produce bags and frozen food bags. Film manufacturers are now using blends of LDPE and LLDPE for these applications, the inclusion of the latter offering opportunities for increased strength and decreased gauge, and thus the consumption of LLDPE is increasing at the expense of LDPE.

Metallocene catalysed grades of LLDPE are also now readily available, offering high puncture resistance and good clarity, and these are finding particular application in the high performance end of the pallet stretch film market, especially for pre-stretch machines. Most stretch film is produced by the cast process (see Chapter 14). The choice of comonomer in LLDPE depends on performance required; octene and hexene offer superior strength but are more expensive than butene LLDPE, hence they are used for more demanding applications.

Collation shrink film for secondary packs uses LDPE and LDPE/LLDPE blends, as well as coextrusions to impart specific slip characteristics and thus ensure the stability of a palletised load. If transparency is an important factor, e.g. for collation packs of bottles of mineral water and soft drinks which are sold directly to the consumer, metallocene grades are suitable, offering opportunities for significant down gauging with no loss of strength.

Pallet shrink wrap film uses mainly LDPE, which may be blended with LLDPE and/or HDPE for improved strength and down gauging. In Europe, pallet stretch wrapping is far more common than pallet shrink wrapping, as the latter requires higher capital investment and is more expensive per pallet due to the amount of film used and the need for energy in the form of heat. However, there are some specific applications where it remains the optimum choice, e.g. securing heavy loads such as glass bottles in transit from the producer to the packer/filler, or for providing good protection against dust contamination for palletised sheets of paper/board in transit from the paper mill to the printer/converter.

One further application of LDPE/LLDPE film in secondary/tertiary packaging is that of pallet stretch hoods. Stretch hooding uses highly elastic film to form a hood which is stretched over the palletised load and pulled down to be secured onto the pallet. It requires no heat (unlike pallet shrink wrapping) and is a faster process than stretch wrapping. Films are usually coextrusions including EVA (ethylene vinyl acetate) copolymers and elastomers.

Plastic sacks are used mainly in the horticulture market (for compost, etc.) and for chemicals, fertilisers, building materials and animal feed. LDPE is widely used, often blended with LLDPE for puncture resistance, and MDPE (medium density polyethylene) and HDPE for added stiffness to aid performance on the filling line. Coextrusions are used to impart the required levels of slip and heat-sealing characteristics.

Apart from film uses, both LDPE and LLDPE are used as heat seal coatings, extruded onto paper, board, other plastic films and aluminium foil, as well as for lamination. One significant market is liquid packaging cartons (see Chapter 10). Rigid packaging uses of LDPE include small, squeezable bottles, tubes, push-in and push-on closures.

High density polyethylene

High density polyethylene is made using a low pressure process and Ziegler-Natta or Phillips initiators to control the chain formation, resulting in a highly linear (unbranched) structure. Metallocene catalysed variants are also available. HDPE is more crystalline than LDPE, and hence is more opaque, more rigid and has a higher tensile strength. It has a good moisture barrier and fair oxygen barrier. T_m is around 135°C and thus it withstands boiling water, which makes it suitable as a heat seal coating for steam sterilisable pouches and as a film for boil-in-the-bag foods.

Most of the applications of HDPE are in rigid packaging such as bottles for milk and household chemicals, as well as heavy duty items such as pallets, drums, crates and intermediate bulk containers. It is prone to environmental stress cracking and this should always be checked prior to selection. In the past it has been used widely for bottles for toiletries, although PET tends to be preferred in this sector due to its excellent transparency. It is also used for short-life screw caps, e.g. for milk and soft drinks bottles. Where screw caps are required for multiple uses, e.g. products such as shampoo and other toiletries, HDPE is liable to break in use and PP is a much better option. HDPE is also used for heavy duty sacks and bags, e.g. fertiliser, sand and aggregate.

Ethylene copolymers

The following ethylene copolymers are included here as part of the polyethylene family, although in usage they fall into the more specialised category of materials considered in Section 13.5.

Ethylene vinyl acetate

Ethylene vinyl acetate (EVA) is a random copolymer of ethylene and varying amounts of vinyl acetate (VA). The VA comonomer interferes with chain packing, reducing crystallinity and thus lowering T_m and improving transparency when compared with LDPE. As the VA content increases, crystallinity decreases, until at 50% the EVA is totally amorphous. Flexibility and toughness at low temperatures are also improved making it a good choice for frozen food bags. It has good hot tack and adhesive strength and a wide sealing temperature range, accounting for its uses as a heat seal layer and in hot melt adhesives.

Ethylene vinyl alcohol

Ethylene vinyl alcohol (EVOH) is another ethylene copolymer, this time using the comonomer vinyl alcohol (produced by the hydrolysis of vinyl acetate). It has excellent barrier to oxygen (less than 2 cc/m^2/day) but the –OH groups make it hydrophilic, i.e. it attracts water, which decreases the oxygen barrier. For the oxygen barrier to be effective, EVOH must be 'sandwiched' to protect it from moisture. This is commonly done by coextrusion, examples being PET/EVOH/PET for bottles for sauces and mayonnaise and/or PET/EVOH/EVA for modified atmosphere packs for processed meats.

Polyvinyl acetate and polyvinyl alcohol

Polyvinyl acetate (PVA) and polyvinyl alcohol (PVOH) are further examples of ethylene copolymers. PVA is used as an emulsion adhesive for bag, sack and carton making. PVOH is produced by hydrolysis of PVA and the strong hydrogen bonding imparted by the –OH groups means that pure PVOH is water soluble. The degree of water solubility is controlled by the amount of hydrolysis. Specific packaging uses for PVOH are in unit doses of detergents, where the entire pack is placed in the washing machine, and for agrochemicals, where the pack is placed into a tank of water and mixed. In both of these examples the advantages are that a measured dose of product is used, with no spillage on decanting and, in the latter case, limited exposure of personnel to what may be a toxic product.

Ethylene acrylic acid

Ethylene acrylic acid (EAA) is, as the name suggests, a copolymer of ethylene and acrylic acid (AA). As the AA content increases, crystallinity decreases (due to interference with chain packing) and heat seal temperature decreases, and the increase in polarity means that adhesive strength increases. Its excellent adhesion to a range of substrates makes it a good choice as the adhesive layer in foil laminates for composite containers, toothpaste tubes and sachets.

Ionomers

Ionomers are unusual in that they have ionic as well as covalent bonds in the polymer chains. They are made by reacting metal salts (commonly Na^{+} or Zn^{++}) with acidic copolymers such as EAA or ethylene methacrylic acid (EMAA). The ionic bonds act like crosslinks between the polymer chains, resulting in tough, puncture resistant materials with excellent heat-sealing characteristics over a wide temperature range, and the ability to seal through contamination. Bonding to aluminium foil and paperboard is excellent. Ionomers also have very good resistance to oily products, making them useful as heat-sealing layers for processed meats. They are also used in rigid form for closures. There is a large range of options from which to choose, the main suppliers in the packaging field being DuPont, under the Surlyn® brand and Exxon Mobil under the Iotek™ brand.

13.4.2 Polypropylene

Polypropylene has the lowest density of the common packaging plastics (Table 13.5), which gives it an economic advantage over other materials. It is formed by the polymerisation of propene and thus differs from polyethylene in that it has methyl groups on the carbon backbone chain. The arrangement of these methyl groups can vary and, as already mentioned in Chapter 12, PP exists in three different tacticities:

- Isotactic: Methyl groups are all on the same side of the chain.

- Atactic: Methyl groups are arranged randomly on both sides of the chain.
- Syndiotactic: Methyl groups alternate around the chain in a regular manner.

The isotactic form is the one most commonly used in packaging and, unless otherwise stated, this is the form referred to in the literature on PP. It is a tougher and stiffer material than the PE family, with good resistance to creep and to environmental stress cracking, and has a good barrier to moisture (see Table 13.4). It has a higher T_m than HDPE (around 160°C) and can be used where HDPE may otherwise fail, e.g. hot-filled bottles and tubs for soups and sauces and steam-sterilised applications.

In contrast, atactic PP is a soft and rubbery, mainly amorphous polymer. Its chief use is in adhesives, although there is some development of atactic/isotactic block copolymers which form thermoplastic elastomers. The third variant, syndiotactic PP has a T_m of around 130°C. It is softer than isotactic PP but still tough and more transparent. Its resistance to gamma ray sterilisation is being exploited in some film applications for medical packaging.

At very low temperatures PP homopolymer becomes brittle and thus is unsuitable for use in long-term deep freeze conditions. To overcome this problem, propylene is copolymerised with ethylene (typically 1–7%), producing polypropylene random copolymers. As well as improved clarity, other benefits are increased strength and toughness, a broader melting range and a lower melting temperature which improves heat sealability. All of these benefits have led to the widespread use of PP copolymers.

The clarity of PP is also improved by adding nucleating agents (which reduce the incidence of crystalline regions) and this is utilised in making contact-clear ice cream containers, for example. Another way to impede the formation of crystallites is to subject the molten polymer to rapid cooling, as in the cast film process, resulting in highly transparent and sparkling films.

Polypropylene is a versatile material, with important applications in both flexible and rigid packs. As shown in Table 13.6, film is the most significant market, followed by thin wall packaging. PP film is usually biaxially oriented (BOPP) and this has become the material of choice for snacks, biscuits, cakes, confectionery and tobacco products, due to its high strength and adequate barrier properties, even at very low gauges. See Chapter 14 for descriptions of the orientation processes.

BOPP has excellent clarity, and can also be produced in pearlised and opaque

Table 13.6 Packaging applications for polypropylene

Pack type	
Film	32%
Thin wall containers	30%
Bottles	5%
Returnable transit packs (RTPs)	6%
Closures	13%
Other	14%

Source: Applied Market Information Ltd (www.amiplastics.com).

forms, giving a wide range of aesthetic effects. It is also produced in grades with good surface smoothness for subsequent metallising, which gives a shiny metallic appearance without the use of aluminium foil, and at the same time improves the barrier properties of the base film. Technical performance such as barrier, heat-seal characteristics and printability can also be improved by coating and coextrusion, and most BOPP is multi-layer, with suppliers offering a number of tailored options to suit a myriad of uses.

While BOPP is the most commonly used PP film, CPP (cast, non-oriented PP) film has important applications. As already mentioned, rapid cooling after casting results in a highly transparent film, used for textile bags and flower/plant packaging. Food packaging uses include retortable pouches.

Thin wall packaging describes thermoformed and injection moulded pots and tubs, such as those commonly used in the dairy industry for desserts, yoghurts and spreadable fats. PP offers good forming characteristics and good strength at a lower component weight, compared with polystyrene, which is its main rival in this sector (see Section 13.4.4). Thermoformed containers are made from sheet produced by cast extrusion, and as with film, coextrusions are possible to tailor the properties to the performance required.

Polypropylene belongs to the polyolefin family of polymers and therefore, like polyethylene has very low surface polarity and thus must be surface treated before printing.

13.4.3 Polyvinyl chloride (PVC)

PVC is made by the polymerisation of vinyl chloride (chloroethene) which is itself made by the chlorination of ethene. The chlorine atoms on the carbon backbone chain account for the much higher weight per unit volume of PVC compared to the polyolefins (see Table 13.5) and their syndiotactic arrangement means that the polymer is largely amorphous, and hence has good optical clarity. It has a good gas barrier and although the moisture barrier is poor, this is improved by coating with polyvinylidene chloride (PVDC) which has the added advantage of being readily heat sealable, a property utilised in blister packs for pharmaceutical tablets. PVC also has very good grease and oil resistance, and hence was the first alternative to glass bottles for cooking oil, and is still used for bath oils. It has a low T_m (around 90°C) and is thus easy to form, leading to its widespread use for thermoformings such as display trays. It also accepts ink readily. See Table 13.7 for the main uses of PVC in packaging.

Table 13.7 Packaging applications for polyvinyl chloride

Pack type	
Thin wall containers (including trays)	49%
Film	44%
Bottles	7%

Source: Applied Market Information Ltd (www.amiplastics.com).

Unplasticised PVC is naturally brittle, and as the proportion of plasticiser increases, so does flexibility. Plasticisers lower the glass transition temperature, thus improving processability, although they also decrease barrier properties, hence there is a wide range of grades available to suit end uses, from rigid bottles for oily products to highly flexible films such as 'cling' film. There is concern about the possible effects of plasticisers migrating into food products and this has led to a decline in the use of PVC in food packaging. A further contributor to this decline is the considerable environmental opposition to PVC because of the production of hydrochloric acid and dioxins on incineration (although these emissions can be abated, given the right choice of technology). Given these concerns, several companies have taken the decision to move away from PVC for packaging applications, although it continues to be widely used in the construction sector (window frames, pipes and cables) and for flooring.

13.4.4 Polystyrene

Polystyrene is the addition polymerisation product of phenyl ethene (commonly known as styrene). It is a highly transparent, glossy material, with a poor barrier to moisture and gases and limited chemical resistance. It softens at around 75°C and is liquid at around 100°C, and is thus easy to form. It accepts ink readily and thus is easy to print using flexographic or gravure printing for films, and dry offset letterpress or screen printing for three-dimensional components. General purpose styrene (GPS), sometimes known as crystal styrene is very brittle and most polystyrene used in packaging is the high impact variant (HIPS) which is a styrene-butadiene copolymer. The butadiene provides flexibility and lowers the softening temperature, and these two improvements account for the use of HIPS in thermoformed thin-wall containers for the dairy market. It is also thermoformed into sandwich packs and trays for salads, and made into biaxially oriented film for bags for fresh salads and other produce. The poor barrier properties are beneficial for products which respire, e.g. fresh fruit and vegetables, as they help to prevent a build-up in the pack of moist air which is conductive to mould growth.

A further application in packaging is expanded polystyrene (EPS). This is a lightweight material with fairly good compression strength and resistance to moisture. It is a good insulator against both temperature change and shock and is used for fast food trays, boxes for fresh fish and for home delivery of chilled and frozen foods, cell-packs for growing plants and as both loose-fill and pre-formed shapes in packaging fragile items such as china and glassware, domestic appliances and electronic goods.

Specialist copolymers of polystyrene are covered in Section 13.5.

13.4.5 Polyethylene terephthalate (PET)

PET is a condensation polymer made from a diacid (e.g. terephthalic acid) and a dialcohol (e.g. ethane 1,2-diol, commonly known as ethylene glycol). The acid and the alcohol first react together to form ester molecules, which are then polymerised, hence the common term 'polyester'. This term refers to a large family of compounds with many diverse applications; PET is the common thermoplastic polyester used in packaging.

PET is available in both amorphous (APET) and crystalline (CPET) forms, with the former being more commonly used. Moisture barrier is about the same as that of LDPE, but gas barrier is higher than most of the common packaging plastics and this can be further improved by metallising with aluminium or by coating with, for example, PVDC or silicon oxide (SiOx). Almost 90% of the PET used in packaging is for bottles, primarily for soft drinks and mineral water which are now routinely packaged in PET rather than in glass, due to the weight savings and associated transport cost savings available. PET bottles are also being increasingly used for household chemicals such as laundry products, where the transparency of APET is often seen as an advantage over both HDPE and LDPE.

A significant growth market for PET is in bottles, jars and other components such as lipstick cases in the cosmetics sector, where the good oxygen barrier provides protection against degradation of oily products and loss of perfume. Early uses tended to be for lower-price products such as shampoo, but now thick-walled jars in transparent and coloured forms are widely used instead of glass for expensive creams. The materials used in this sector are mainly copolyesters such as polyethylene terephthalate glycol (PETG), made by varying the starting diacids and dialcohols and variants are available for injection and extrusion blow moulding, as well as for thin-wall and thick-wall containers.

A potential growth market for PET is in beer bottles, with the commercial availability of surface coatings and multi-layer technology to improve gas barrier. At the current time the use of PET for beer is mainly confined to outdoor events, where safety is the main driver, but developments such as PET/PEN (polyethylene naphthalate) blends and coextrusions could bring PET into the mainstream beer market as a realistic alternative to glass.

Flexible packaging uses of PET include biaxially oriented film for pouches and lids for ovenable ready meals. The orientation improves stiffness and the high clarity enhances visual impact, especially in laminates where the PET is reverse printed. PET sheet is thermoformed into trays for salads. The crystalline (CPET) variant is opaque and is used for trays for ovenable ready meals, due to its high temperature resistance.

Uses of recycled PET (r-PET) for primary packaging are increasing, both for food and non-food products. As with all developments, compatibility and shelf life studies are essential. A recent study in the Cosmetic Science department at the London College of Fashion showed encouraging results using PET bottles containing 30% post consumer recyclate (PCR) in contact with common cosmetics such as baby oil, shower gel and shampoo (Talarek, 2011). It is thought that higher PCR content would also be compatible with these products, although the decrease in bottle clarity may be aesthetically unacceptable.

13.5 Specialist polymers used in packaging

Table 13.8 lists the materials which fall into this category. Most of these materials are engineering polymers and their main uses are in markets such as automotive, aeronautical, electronic and others, with packaging end uses representing a small percentage of overall consumption. They are invariably much more expensive than the commodity polymers discussed in the previous section, and are selected for packaging applications only when the commodity polymers do not have the required technical performance, and the product value justifies the additional cost. (Note that EVA, EVOH, PVA, PVOH, EAA and ionomers have already been discussed in Section 13.4.)

13.5.1 Styrene copolymers

In this category the main copolymers used in packaging are styrene acrylonitrile (SAN) and acrylonitrile butadiene styrene (ABS), along with some specialist variants.

SAN is a copolymer of styrene and acrylonitrile (CH_2=CHCN) in a ratio of around 3:1. It is amorphous, rigid and has good resistance to acids, alkalis, oils and greases. Its high transparency and easy surface printability make it a good choice for cosmetics compacts and jars, and it is available in a range of colours and grades. At this ratio of styrene to acrylonitrile it has a poor gas barrier, but this can be improved by increasing the acrylonitrile content.

ABS is a random styrene acrylonitrile copolymer grafted to butadiene (see Chapter 12). Like SAN, it has good chemical resistance, is readily printable and has good resistance to environmental stress cracking. Many variants of composition are available to suit the required technical performance and aesthetic qualities. ABS is naturally opaque, but the variant methyl methacrylate acrylonitrile butadiene styrene (MABS) is highly transparent. Both materials are used in the cosmetics sector for

Table 13.8 Specialist polymers used in packaging

Ethylene vinyl acetate	EVA
Ethylene vinyl alcohol	EVOH
Polyvinyl acetate	PVA
Polyvinyl alcohol	PVOH
Ethylene acrylic acid	EAA
Ionomers	
Styrene acrylonitrile	SAN
Acrylonitrile butadiene styrene	ABS
Polyvinylidene chloride	PVDC
Polyethylene naphthalate	PEN
Polyamide	PA
Polycarbonate	PC
Fluoropolymers	
Thermoplastic elastomers	TPEs
Cyclic olefin copolymers	COCs
Liquid crystal polymers	LCPs
Thermosetting plastics	
Cellulose materials	

mascara and lipstick cases, compacts and closures. ABS is also suitable for tubs for butter, margarine and desserts such as yoghurt, where it offers improved toughness compared to polystyrene, albeit at a higher purchase price.

As already noted, increasing the acrylonitrile component in these copolymers improves the gas barrier and one example of this is Barex®. This is a copolymer of acrylonitrile and methyl methacrylate (75:25 ratio) and nitrile rubber; it has excellent gas barrier, good chemical resistance and good sealability, making it useful for packaging meat and cheese. It also has excellent impact strength, withstands repeated flexing without cracking and is resistant to sterilisation by gamma radiation and ethylene oxide, making it a good choice for demanding applications in the medical and pharmaceutical sectors.

13.5.2 Polyvinylidene chloride (PVDC) copolymers

PVDC is made by the addition polymerisation of 1,1-dichloroethene (vinylidene chloride). The homopolymer is very difficult to process as it decomposes below its melting temperature. It thus has no commercial importance and all the PVDC used in packaging is copolymerised with vinyl chloride or alkyl acrylates (e.g. methyl acrylate). The most useful properties of these copolymers are excellent resistance to oils and fats, high gas barrier and heat sealability. They can be used as surface coatings, in coextrusions and as films. Coatings can be water-based (e.g. PVDC/methyl copolymers) and solvent-based (e.g. PVDC/acrylonitrile copolymers) and provide a cost effective way of improving the barrier properties of PP, PET, etc., films, and of enhancing the performance of paper and board. Coextrusions of PVDC copolymers and polyolefins are suitable for multilayer films for products such as meat and cheese, and single layer PVDC copolymer films can be used alone as food wrapping and in laminates wherever moisture and gas barrier are important requirements.

As with PVC, there are environmental concerns about the use of PVDC and these have prompted companies to seek out alternatives. EVOH is one such alternative, especially with regard to gas barrier although, as already noted, it cannot be used as a coating.

13.5.3 Polyethylene naphthalate (PEN)

PEN is a condensation polymer of ethylene glycol and naphthalate dicarboxylate. It has been available since the 1980s and PEN film is used in electrical insulation. Packaging uses are limited as yet, almost certainly due to its high price, although it has significant advantages over PET in the drinks bottle market, and refillable PEN bottles for beer have been launched in Denmark and for fruit juices in Germany. The advantages of PEN homopolymer over PET are its higher resistance to heat and 4–5 times better barrier to moisture and gases. It also blocks out UV light. If the end use demands an improvement over PET without the full properties of PEN homopolymer, a cost effective solution may be found in the range of PEN/PET copolymers and blends available.

13.5.4 Polyamide or nylon (PA)

Polyamides are condensation polymers made from diamines and diacids and are named according to the number of carbon atoms in the starting materials, e.g. Nylon 6,6 is produced from hexamethylene diamine $H_2N–(CH_2)_6–NH_2$ and 1,6-hexanedioc acid $HOOC–(CH_2)_4–COOH$ (commonly known as adipic acid). They can also be made from amino acids, in which case they have just one number, representing the number of carbon atoms in the starting substance, e.g. Nylon six is made from caprolactam, a cyclic compound with a total of six carbon atoms and Nylon 11 is made from the straight-chain amino undecanoic acid $H_2N–(CH_2)_{10}–COOH$.

Polyamides are mostly used in engineering applications, due to their strength and toughness, and good heat and low temperature resistance. Gas barrier is very good, but the material is moisture sensitive and as the moisture level increases the oxygen barrier decreases. Some grades have excellent clarity. Packaging applications mainly utilise the high oxygen barrier properties of Nylon 6, for example in packaging of frozen meat joints, where the low temperature resistance and puncture resistance make this an ideal laminate (with LDPE or EVA for heat sealability). If exceptionally high mechanical strength and heat resistance are important, Nylon 6,6 may be a better option.

13.5.5 Polycarbonate (PC)

Polycarbonate is a polyester made by the condensation of carbonic acid HO–CO–OH and bisphenol A $HO–(C_6H_6)–C(CH_3)_2–(C_6H_6)–OH$. It is glass clear and has exceptional impact resistance and good UV resistance, properties which account for its uses in glazing, safety spectacles and in automotive applications such as headlamp lenses. It is also heat resistant and readily sterilisable, which explains its main packaging use for returnable containers for office water dispensers. These large containers are subjected to rough handling and can be repeatedly sterilised without deterioration. Other packaging applications are currently limited, due to the high resin price and the availability of alternatives such as PET.

13.5.6 Fluoropolymers

Fluoropolymers are addition polymers of halogenated alkenes. Perhaps the best-known one is polytetrafluoroethylene (PTFE), better known under its trade name Teflon®, which is highly crystalline, inert and has a very low coefficient of friction and high melt temperature, accounting for its use as a non-stick coating. Polychlorotrifluoroethylene (PCTFE), under the trade name Aclar®, is used in pharmaceutical packaging applications such as thermoformed blisters and novel drug delivery systems. It has exceptionally high moisture barrier and when laminated to Barex® (noted for its high gas barrier – see above) the combined material can provide the long-term shelf stability demanded in such applications, along with justification for its high cost.

13.5.7 Thermoplastic elastomers (TPEs)

TPEs have already been discussed in Chapter 12. They combine the easy processing of thermoplastics with the elastic properties of rubber. The ability to recover from deformation and good chemical resistance make TPEs highly suitable for closure wads and plugs, and a thin layer of TPE on the outer surface of containers and closures provides a soft, rubbery feel which gives good grip, as well as aesthetically pleasing tactile properties. See Chapter 12 for a review of the different types available.

13.5.8 Cyclic olefin copolymers (COCs)

COCs are produced by addition polymerisation of a cyclic olefin (such as cyclopentadiene) and a conventional straight chain olefin such as ethene, using conventional or metallocene initiators. They have been available commercially since the 1990s, although their high cost has limited their use in packaging to specialist pharmaceutical and medical applications. High strength and clarity, combined with excellent moisture barrier make them viable alternatives to glass for items such as pre-filled syringes, vials and ampoules for injectables. There are grades suitable for film extrusion, bottle blowing and injection moulding and they can be used in blends with polyethylene and in individual layers in coextrusions. Resistance to acids, alkalis and polar solvents is good.

13.5.9 Liquid crystal polymers (LCPs)

Liquid crystal polymers are thermoplastic polyesters copolymerised from rigid and flexible monomers. The rod-like rigid segments are connected by flexible segments which allow the materials to flow on heating. During processing, e.g. into film or injection moulded parts, the rigid segments align in the liquid state and retain their crystal-like spatial arrangement on cooling. This results in materials with high tensile, impact and tear strength, high melting point and excellent barrier to gases and moisture. They have been commercially available since the 1980s and used in applications such as surgical devices, audio visual components and business machines. Flow properties are excellent and thin-walled sections can be moulded to close tolerances. Packaging applications are limited as yet, and are likely to be based on the very high barrier properties, e.g. LCPs are available with an oxygen barrier around six times better than EVOH, without the associated deterioration in humid conditions.

13.5.10 Thermosets

As stated in Chapter 12, in thermosets the polymer chains are arranged in a matrix fashion, with strong bonds called 'crosslinks' connecting them. As a result, they are dense, rigid materials with excellent chemical resistance and high heat resistance. The crosslinking takes place during polymerisation and thermosets cannot be reshaped once formed, hence they cannot be recycled. Thermosets such as phenol formaldehyde were amongst the first plastics used (see Table 13.1) but their usage in packaging declined markedly with the commercial availability of thermoplastic resins which offered easier processing at lower price. Both phenol formaldehyde and urea formaldehyde are still used for screw-threaded closures especially where high chemical resistance is important, e.g. laboratory reagents such as strong acids and alkalis. Also, unlike thermoplastics, thermoset closures are not prone to creep and the associated loss of torque over time. Other advantages are the minimal shrinkage on cooling, which means that thick-walled sections do not show sink marks, and the fact that the thermoset forming process allows very high precision and dimensional accuracy, along with high definition. This accounts for its use for closures with an embossed, highly detailed brand logo, as used on some alcoholic spirits.

Other packaging applications for thermosets are crosslinked acrylic, polyurethane and epoxy lacquers and adhesives.

13.5.11 Cellulose materials

As mentioned in Chapter 10, cellulose fibre can be made into cellulose film and this was the first transparent packaging film, widely used for confectionery, snack foods, biscuits, cigarette overwrapping, etc. It was also the material of choice for adhesive tape. The advent of polypropylene film in the 1960s changed this due to its lower cost, and the use of cellulose materials in packaging has now declined to a few specialist applications. This section provides an overview of cellulose film and cellulose esters.

Cellulose materials are derived from cellulose plant matter, usually wood pulp from managed forests and thus they can claim to be made from renewable sources. In technical performance they possess many of the properties of paper, such as excellent folding characteristics and the ability to maintain a fold (deadfold), easy printability and freedom from static. Like paper, uncoated cellulose materials have no heat-sealing capability and they absorb moisture (due to the high number of hydroxyl groups), although all these issues can be addressed by the use of appropriate coatings.

Cellulose film is commonly known by its trade name Cellophane™, and is widely used in packaging for twist wrapping of confectionery. This is due mainly to its deadfold properties, although the excellent clarity, sparkle and availability in a range of attractive colours are also important factors. In addition, the fact that the material is static free (unlike polypropylene, for example) is a key benefit for high speed packaging machines which can be running at 1,000 pieces per minute, where the build-up of static would lead to packs sticking together, causing line stoppages.

As stated, cellulose film can be coated to impart specific properties and Cellophane™ is available with copolymer, nitrocellulose or PVDC coatings, depending on the level of moisture barrier, gas barrier, heat sealability and thermal stability required. Films can be used alone or in laminations and typical end uses in addition to confectionery include wrapping of bakery goods and soft cheeses. Microwaveable films are available with semi-permeable coatings which allow some ventilation during heating, making them ideal for pastry products such as pies and quiches where the release of built-up water vapour maintains the product crispness.

NatureFlex™ is a more recent cellulose film which, as well as being based on renewable resources, has the added benefit of being compostable to EN 13432. For the purposes of this chapter, it is categorised as a bio-based polymer and will be discussed in Section 13.6.

Cellulose esters used in packaging include cellulose acetate (CA) and cellulose acetate butyrate (CAB). CA is used as a clear window in paperboard cartons, especially when moisture permeability is required, such as for cakes where the moisture would otherwise be trapped inside the carton and cause fogging, obscuring the product. It can also be used to make 100% transparent cartons as gift packs for products such as cosmetics. CAB has greater resistance to moisture permeability and is used for clear rigid tubes suitable for a range of products such as confectionery, soap and bath products.

13.6 Bio-based polymers

Most polymers discussed so far in this chapter are derived from crude oil. They are long life materials, destined to provide product protection and preservation, and to withstand degradation. They offer reliability in service and will last for many years, usually far longer than the products they contain. This longevity is desirable in the sense that the consumer can confidently purchase a plastic bottle of milk, shampoo or cooking oil, knowing that the bottle will remain in acceptable condition until the contents are used up. But resistance to degradation becomes a negative property if and when the bottle is taken to landfill at the end of its useful life, where it could remain almost unaltered, probably for hundreds of years. Of course, as already discussed in Chapter 5, there are alternatives to landfill, such as recycling into the same or different end uses and thermoplastics are ideal for this, being readily melted and formed into new structures. Other end-of-life options are reuse (e.g. plastic pallets and drums) and the production of energy from waste plastic.

Returning to the resources used to make most plastic packaging, i.e. crude oil, it should be remembered that plastic packaging is not the major end use of oil-derived products, and should not be held responsible for fossil fuel depletion. Nevertheless, concerns about this have instigated efforts to explore the use of alternative starting materials such as agricultural crops, and it is this category of materials which will now be reviewed.

Bio-based polymers are derived from plant matter, commonly known as biomass (although 'biomass' can also mean animal-derived material). As the crops used, for example maize and sugar cane, can be replanted, these polymers can claim to be made from readily renewable resources, unlike crude oil which takes millions of years to form. Using such renewable resources would appear to be a positive step, although agriculture itself is not free from negative environmental effects. Land has to be prepared for farming, pesticides may have to be used and transport of crops is required, thus generating carbon dioxide emissions. There is also the consideration of using land for the production of polymers, at the expense of food production.

To the general public, the word 'biopolymer' has become synonymous with biodegradable but this is misleading and confuses polymer sourcing (i.e. crop-based) with polymer functionality. This chapter adopts the British Plastics Federation's approach, by using the sub-title 'bio-based polymers' and differentiating between natural bio-based polymers and synthetic bio-based polymers. For example, sugar extracted from crops is used to make bioethanol which can be used as the starting material for making ethylene and polyethylene. Polyethylene produced by this route is a synthetic bio-based polymer, having the same performance properties as the oil-derived polyethylene already discussed, which is not biodegradable. The claim 'derived from renewable resources' may be made, but not the claim of biodegradability.

Clarification must also be made between oxodegradable and biodegradable polymers. Oxodegradable refers to oil-derived thermoplastics such as PE and PP with the addition of initiators which accelerate the breakdown of the backbone carbon chains when the plastic components, e.g. film or bottles are exposed to air, causing them to break down into fragments. This breakdown starts when the components are produced and takes around six months, depending on the exposure conditions.

Biodegradation refers to the process of breakdown of organic matter into its basic raw materials by the action of microorganisms. The compostability standard EN 13432 lays down a set of standard conditions (e.g. time, temperature, relative humidity) under which biodegradation must take place. It also defines the acceptable level of breakdown in terms of particle size and impact on the compost and the environment (e.g. production of heavy metals) for a material to be declared compliant.

A brief overview of the sources and properties of some of the bio-based polymers currently available now follows, although this is not presented as an extensive study and readers are advised to seek out more detailed information for specific applications.

There are two main ways of treating biomass to make bio-based polymers. Either it is processed to extract the natural polymers such as the polysaccharides starch or cellulose which are present in all plant matter, or methods such as hydrolysis, fermentation, or other microorganism attack are used to produce monomers, which in turn are then synthesised into polymers, e.g. lactic acid to polylactic acid (PLA).

Starch-based polymers are commonly derived from maize, although other crops such as potatoes and rice are also used. Just one example of commercially available starch-based materials in Europe is the Mater Bi® range from Novamont. These plant-derived materials conform to EN 13432 with respect to compostability, can be processed using traditional plastics processing techniques such as extrusion and injection moulding, and are readily printable without the need for surface treatment. A wide range of grades is available for food and non-food uses and includes flexible packaging and thermoformed trays, as well as coatings for paper and board, and foams for cushioning against shock. Laminates are available where moisture and gas barrier are important requirements, e.g. for biscuits and snacks.

Reference has already been made to the compostable range of cellulose-based films under the NatureFlex™ brand, from Innovia. They are made from renewable resources (wood pulp from managed forests) and in their uncoated form have excellent transparency, deadfold, anti-static and easy-tear properties. Coated grades give enhanced performance such as moisture barrier, heat sealability and resistance to grease and oil. Metallised grades are also available, making the range serious competitors to oil-derived polypropylene in the bakery, overwrapping, fresh produce and confectionery sectors, for companies wishing to make both renewable resources and compostable claims.

PLA is produced by fermentation of biomass, using microorganisms to convert the starch to lactic acid monomer. Maize is commonly used as the starting material, although sugar cane/beet and wheat can be used, indeed any crop with a sufficiently high sugar content in the plant starch. Lactic acid exists as two optical isomers, the D and L forms, depending on the spatial arrangement of the groups around the central (chiral) carbon atom. PLA made from 100% L-lactic acid is highly crystalline (known as C-PLA) while copolymers of the L and D forms are more amorphous and thus more transparent. PLA resins are available for extrusion into film, thermoforming into pots and injection moulding, although processing equipment designed for conventional polymers such as PET may need modification. Generally, PLA has similar barrier properties to polystyrene and current uses include bags and thermoformed tubs and pots for fresh produce. Non-packaging uses include disposable cutlery and other catering items.

With regard to product compatibility, initial studies conducted in the Cosmetic Science department at the London College of Fashion showed some softening of PLA bottles and film in contact with shampoo, although contact with baby oil appeared to have no detrimental effects (Talarek, 2011).

At the end of life, PLA is compostable in industrial facilities, but not in home composting due to the high temperature (above 50°C) and humidity required.

A further category of bio-based polymers is the generic class of copolyesters known as polyhydroxyalkanoates (PHAs). These are commonly made up of the simplest PHA, polyhydroxybutyrate (PHB), copolymerised with other hydroxyalkanoates such as hydroxyvalerate (PHBV). PHAs can be made directly by fermentation, without going through the polymerisation stage as used in the production of PLA. They are generally tough materials, with high temperature resistance, and grades are available for film and sheet extrusion, and injection moulding.

13.7 Conclusion

Compared with oil-based polymers, bio-based polymers are in their infancy and are currently used in niche rather than mass packaging markets. Global production is projected to increase from 700,000 tonnes in 2010 to 1.7 million tonnes by 2015, up from 262,000 tonnes in 2007. However, even the 2015 projection represents <1% of annual plastics consumption (tacooper@post.com; www.pcn.org/cooper.htm). Whilst there are sophisticated manufacturing facilities and high levels of capital investment, these are just a fraction of what has been expended over the past 60+ years of oil-derived polymer production; hence resin prices are relatively high. However, as technologies develop and demand increases, prices may become more comparable. Increased demand could be brought about due to pressure on mainstream brand owners by the 'green' consumer and government policies.

13.8 Sources of further information and advice

Baner, A.L. and Piringer, O. (2008) *Plastic Packaging Materials for Food*. Wiley, New York.

Baner, A.L. and Piringer, O. (2008) *Plastic Packaging: Interactions with Food and Pharmaceuticals*. Wiley, New York.
Giles, G. and Bain, D. (eds) (2000) *Materials and development of plastics packaging for the consumer market*. Wiley, Oxford.
Giles, G. and Bain, D. (eds) (2001) *Technology of plastics packaging for the consumer market*. Wiley, Oxford.
Hernandez, R., Selke, S. and Culter, J. (2000) *Plastics Packaging*. Hanser, Munich.
Nicholson, J. (2011) *The Chemistry of Polymers*, 4th edn. RSC Publishing, Cambridge.
Talarek, K. (2011) Sustainability in Cosmetic Packaging, undergraduate thesis, London College of Fashion.

In addition to the above texts, the British Plastic Federation (www.bpf.co.uk) is a valuable source of information on all aspects of plastics, including material properties, industry applications and forming methods.

Other useful sources of information include:

- http://www.britishplastics.co.uk
- http://www.incpen.org
- http://www.packagingdigest.com
- http://www.packagingfedn.co.uk
- http://www.packagingtoday.com
- http://www.pafa.org.uk
- http://www.plasticsinpackaging.com

Applied Market Information Ltd (www.amiplastics.com) is a recommended source of market data for plastics used in packaging, specifically the following reports:

- *Plastics Packaging Producers – A Review of Europe's Largest Players 2011*
- *European Plastic Industry Report 2011*

Note: Sources used in the preparation of this chapter also include teaching and learning materials written and used by the author in the delivery of courses to a number of organisations, such as the Packaging Society, Loughborough University, University of Warwick, University of Bath and London College of Fashion (University of the Arts London).

14
Plastics manufacturing processes for packaging materials

A. RILEY, Arthur Riley Packaging Consultant International, UK

Abstract: Polymers are finding new opportunities in packaging every day. The inventiveness of the polymer producer and the converting machinery manufacturer has seen plastics become the most used packaging material on a value basis. Plastic packaging is replacing metal retort cans, glass bottles, paperboard cartons and even corrugated cases. It provides barrier, ensuring food is kept safer for longer, reduces the weight of packaging, provides convenience, transparency where required, and still only uses less than 4% of oil resources. This chapter will provide the understanding of how polymers can be used on their own, or combined together to form packaging for all needs.

Key words: moulding, extrusion, thermoforming, coextrusion, laminating.

14.1 Introduction

This chapter will concentrate on the forming of thermoplastic packaging components from oil-based polymers. Polymers, as covered in the last two chapters, are highly versatile. A major advantage of plastics is that they can be combined together to provide packaging which is lightweight yet provides the barriers required, is tough and strong yet can be made easy to open. Most plastics used today are copolymers rather than homopolymers and are increasingly supplied in multiple layers rather than as monolayer. Using special techniques, plastic components can be produced to closely rival the absolute barriers available from metal and glass. This chapter will examine the processes required to make flexible, semi-rigid and rigid packaging formats for a variety of applications and the controls that are required to ensure consistency of supply is achieved.

To convert polymers into useful packaging requires specialised equipment and an understanding of their chemistry and properties. Polymers are converted into films, coatings, trays, bottles, jars, cans, closures and blister packs. They are combined together through coextrusion, coinjection and lamination processes; combined with paper and aluminium foils; coated with other polymers and undergo many chemical and physical treatment processes; all with the aim of changing their properties to suit the needs of the marketplace.

14.1.1 Selection of materials

When developing any new pack, there are some basic considerations with respect to the product and the pack which influence the choice of packaging materials, in this instance the polymer(s) that may be suitable. For example:

What aspects of the product are important?

- What are the barrier requirements – gas, moisture, alcohol, UV, etc.?
- Is the product likely to be aggressive to the packaging – acidic, alkaline, greasy, etc.?
- Is the product hazardous or dangerous – poisonous, high/low pH, etc.?
- What is the expected shelf life of the packed product?
- What are its physical properties – solid, liquid, gas, powder gel, flake, etc.?
- Does it need to be visible through the packaging?
- At what temperature will the product be filled – hot, warm, cold?
- At what temperature will the product be stored – ambient, chilled, frozen?

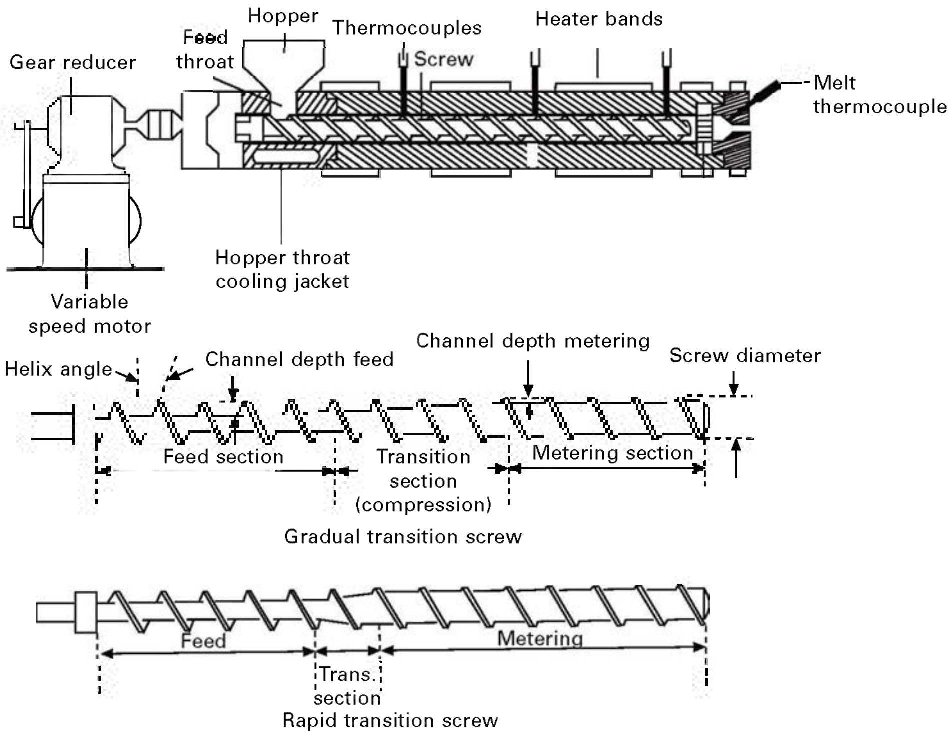
What aspects of the packaging are important throughout the expected life of the product?

- How many size variants are there going to be?
- How many of each variant do I require per annum?
- How soon do I require the packaging?
- Is it going to be a flexible or rigid container?
- What shape is it going to be?
- Is absolute clarity important?
- What quality of decoration is required?
- What temperatures does it have to withstand?
- What type of closure/closing mechanism will be used?
- What surface finish is required?
- Does it require tamper evidence?
- Does it have to meet child safety requirements?
- Will it meet product contact regulations?
- Is it environmentally responsible?
- What can I afford to pay?

The reason for asking these questions is that polymers, though excellent packaging materials, are not as definitive as paperboard, metal or glass in their absolute properties. Paperboard has little or no barrier to gas and moisture; glass, and metal (over 20 µm in gauge for aluminium) are total barriers and metals provide a total barrier to UV light. Polymers have a wide range of properties, depending on their chemical structure, the materials and the coatings added and how they are converted into packaging materials, and thus there are far more variables to consider. See Chapter 13 for more detail about the range of materials available.

14.2 The plasticating extruder

Excluding regenerated cellulose film (e.g., Cellophane™), rotational moulding and the thermosetting materials, all thermoplastic materials are converted using one or more plasticating extruders (Fig. 14.1). The polymer resin, which must be pre-dried if necessary (e.g., PET, PLA and PA) is fed into the hopper of the plasticating extruder, together with any additives such as colour or process and performance



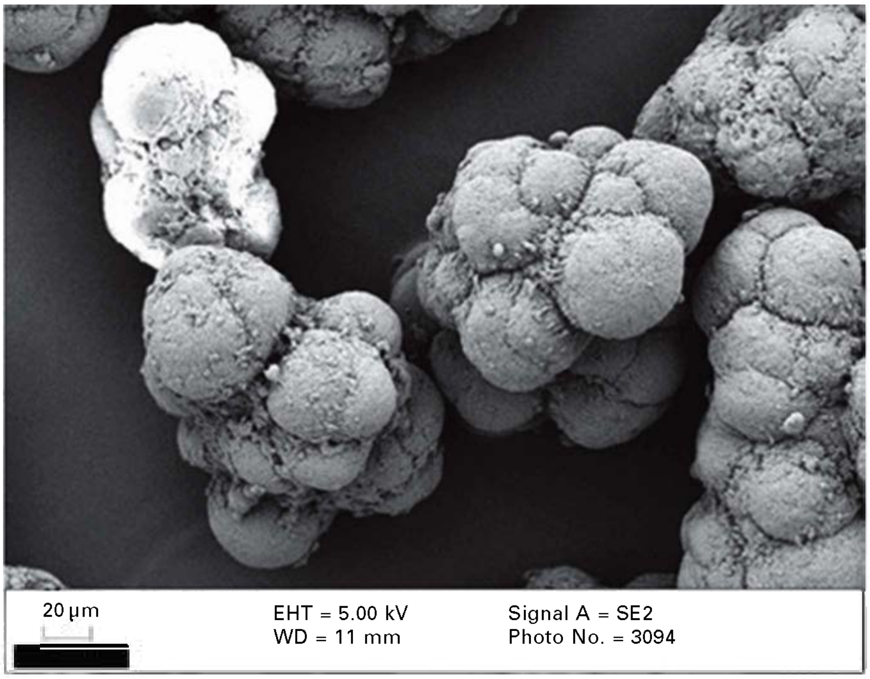
14.1 Plasticating extruder.

aids. See Chapter 12, Section 12.8.9 for a list of typical additives and their functions.

Most resins are in the form of small pellets and are delivered to the converting company either in bulk, in which case they are blown into storage silos, or, for smaller quantities of specialised materials, in 25 kg sacks or larger intermediate bulk containers (IBC). Whatever the delivery format, there must be an incoming quality assurance process to ensure the resins, and the additives, are correct to the relevant specification.

New technologies are being developed to control the particle size of functional fillers, such as carbon black (anti-static) and clay (improved barrier). These particles are nano in size, the filler being reduced to this size within the process, thus reducing any potential health hazards. They are exfoliated onto the polymer surface prior to the polymer being added to the extruder (Fig. 14.2).

The polymer and additives travel along the heated barrel of the extruder. Different temperatures are applied to separate zones down the length of the outside of the extruder. These heater bands ensure that sufficient heat energy is applied to the resin, melting it prior to it reaching the breaker plates and filters. The breaker plates and filters are situated between the end of the screw and the melt thermocouples. The filters are there to ensure unmolten polymer (often high molecular weight polymer, known as gels) and debris are held back and do not contaminate the component.



14.2 The use of carbon black nanofillers to produce anti-static polyethylene carbon nanocomposites (reproduced courtesy of Polyfect Solutions Limited; www.polyfectsolutions.com).

The resin enters the throat of the extruder and is immediately transferred down the barrel by the screw. The screw is designed so that the core diameter increases along its length. This is to ensure that as the resin melts the decrease in occupied volume is accounted for so that the polymer melt continues to be worked, providing most of the energy to change the polymer from solid to liquid. To keep the feed hopper cool and to ensure the polymer does not overheat and therefore degrade, cooling systems are placed around the barrel alongside the heater bands.

Temperature control of the polymer melt is very important. There are normally three to eight temperature zones, depending on the size of the extruder. The heating is controlled by electric heating bands and the cooling by forced air or chilled water contained in pipes. The die has separate heating zones (no cooling required) to control the temperature of that area independently (Table 14.1).

Polymers melt at different rates. The more crystalline the polymer, the shorter the temperature range from start to completion of melting and therefore the quicker the volume loss. Extrusion screw profiles are designed for specific polymers (Fig. 14.1 shows the difference between a gradual and rapid transition screw). Some polymers, for example PVC (polyvinyl chloride) and PVA (polyvinyl acetate), give off acidic fumes when processed through the extruder, therefore extruders and extruder screw and parts need to have special coatings (e.g., chromium plate) to ensure the steel is not subjected to excessive wear.

Pressure control is also critical. The required pressure depends very much on

Table 14.1 Plastic conversion process: process temperatures for some common thermoplastics

Polymer	Acronym	Processing temperature (°C)
Low density polyethylene	LDPE	150–315
High density polyethylene	HDPE	200–280
Polypropylene	PP	205–300
Linear low density polyethylene	LLDPE	190–250
Polyethylene vinyl acetate	EVA	150–205
Polyethylene vinyl alcohol	EVOH	200–220
Ionomer	None	180–230
Polystyrene	PS	180–260
Polyvinyl chloride	PVC	160–210
Polyethylene terephthalate	PET	260–280
Polycarbonate	PC	245–310
Polyamide	PA	240–290

the melt viscosity of the polymer and the forming process. For example, injection moulding requires high pressure to force the molten material through a small orifice whereas the relatively wide die used in extrusion moulding means less pressure is needed. Pressure can build up inside the extruder and in certain circumstances, if not controlled, be high enough to cause an explosion. Extruders are equipped with safety devices which rupture if the pressure builds to a dangerous level. Pressure fluctuation also leads to inconsistent output leading to inconsistency in the formed components.

The extruder feeds a die, which defines the shape and/or quantity of polymer which is fed from the extruder. The die can be a simple slot or annular die form, used for cast sheet and film manufacture, or more complicated to manufacture a wide variety of solid and hollow profiles. For coextrusion processes there are multiple extruders feeding into one die. Extruders for injection moulding are of a different design and are covered later in this chapter.

14.3 Sheet and film extrusion

Sheet is thicker than film, but there is no numerical value to define this. Sheet plastic as used for thermoforming is mainly, but not exclusively, made by the cast extrusion method. Films can be made by two main methods:

- cast extrusion, using a slot die
- blown extrusion, using an annular (ring) die.

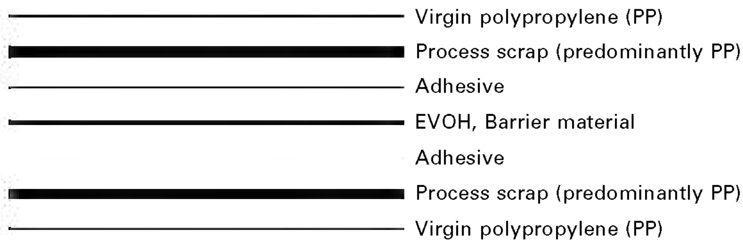
There is little difference in the properties of the film produced by each method, although mono orientation is difficult in blown extrusion and the optical properties of blown film can be less than cast. However, the MFI (melt flow index) and melt strength of a polymer affect its suitability for each process. Melt flow index is a measure of the resistance to flow (viscosity) of the polymer melt at a given temperature under a given force for a predetermined period of time.

The polymer's molecular weight and molecular weight distribution have a direct influence on the MFI: the higher the molecular weight of the polymer the higher the viscosity; the less the polymer flows over a given time, the lower the MFI for any individual polymer. The wider the molecular weight distribution the less resistance to flow; the more material flows over a given time, the higher the MFI. PET homopolymer and PP homopolymer both have low melt strength which makes it difficult to produce either of them using the conventional blown film process, where the bubble is blown upwards. Thus PET is more commonly made using the cast process, and while PP is made using the blown process, it requires a special adaptation to be successful (see later).

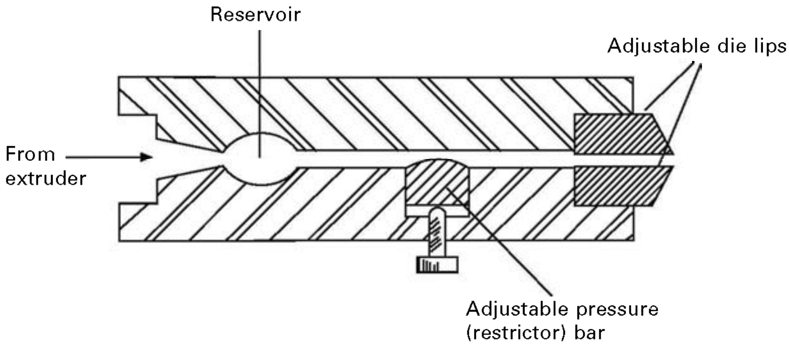
14.3.1 Cast sheet and film extrusion

The cast extrusion process can be used to produce film or sheet as a monolayer or a multilayer coextrusion. Multilayer coextrusion requires one extruder for each different type of polymer used. The number of polymers required is often greater than the number of functional polymers used, as tie layers (adhesive) are required where two incompatible polymers (e.g. EVOH and PP) are adjacent to one another in the multilayer construction. The molten polymer is transported by the extruder(s) into a slot die. It is here where the polymer layers combine as shown in Fig. 14.3.

The slot die in Fig. 14.4 has a narrow opening, which is adjustable and controls the flow rate as well as the initial thickness of the emerging film. There is also a



14.3 Typical PP/EVOH/PP barrier layer coextrusion for a thermoform sheet (including process scrap).

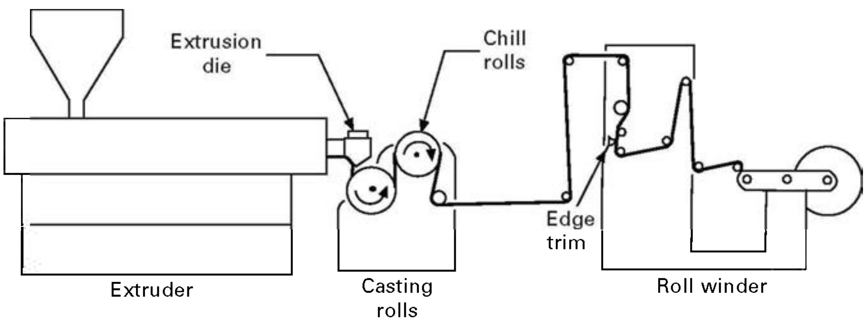


14.4 Cross-section of a slot-orifice die.

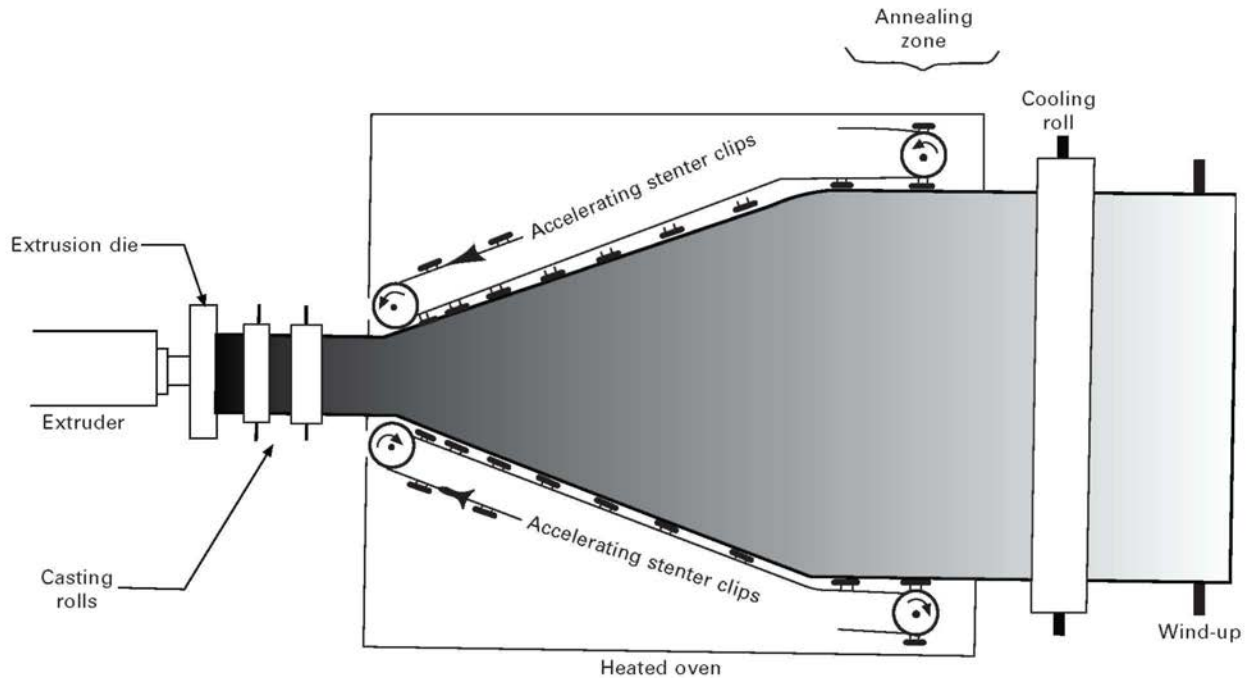
reservoir to help prevent polymer surge through the die, which would result in uneven film thickness and thus uneven performance in use. The polymer is extruded through the slot die which is often a series of small slots adjacent to one another rather than one wide slot, and falls onto large chilled metal rolls to form either sheet or film. Providing the film or sheet are not stretched, there is no orientation of the material (see below). It remains the same width and thickness as controlled by the slot die and has no stiffness, stress or other change to its physical and barrier properties (see Fig. 14.5).

For sheet applications the plastic melt is often extruded onto a temperature controlled three-tier calender stack instead of a chill roll. This smoothes out the surface of the sheet and adds a textured finish if required. The calendered sheet is then cooled by passing through a number of chill rolls or a quench tank, before being wound up ready for despatch for further conversion such as thermoforming into pots and tubs. In some cases, especially when using polypropylene homopolymer which has a low melt strength, it is better to extrude the sheet in line immediately before the thermoforming process. This overcomes the difficulties in controlling the re-heated web on a conventional thermoformer, fed with unmolten preformed sheet requiring reheating.

Film properties can be improved by physically orientating the film in one or two directions (as mentioned in chapter 12) (see Fig. 14.6). Mono-orientation can be achieved by pulling the film in the machine direction (MD) at a faster rate than it is being extruded, i.e. the take-off speed is increased. This realigns the polymer molecules in the direction of stretch, rather than leaving them in their 'natural' random state. Stretching can occur immediately the melt comes into contact with the chill roll or, more commonly, after the first chill roll, often requiring reheating before it is stretched. Mono-orientated film can also be produced by using the stentering method, which stretches and orientates the film in the cross direction (CD). Mono-oriented film is used for shrink sleeve and roll on shrink on labels and pallet strapping. If both orientation mechanisms (MD and CD stretch) are performed in one process, the film becomes biaxially oriented. This method is commonly used to manufacture polypropylene (BOPP) and polyester films. The film is stretched in the machine direction first; grips then take hold of the edges of the film and gradually stretch it in the cross direction. Films can also be stretched in both directions simultaneously.



14.5 Cast-film extrusion line.



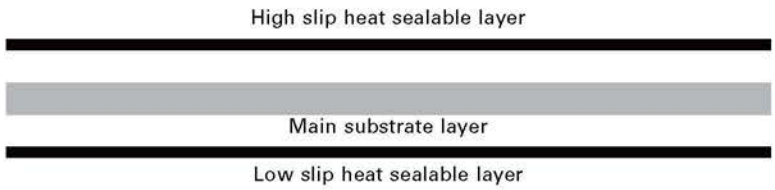
14.6 Orienting cast film: clips grasp the film along each edge and stretch it in the cross direction, while acceleration in the machine direction orientates the film in the machine direction.

If the polymer being orientated is crystalline it must be below its melt temperature (T_m) but higher than its glass transition temperature (T_g) to maximise orientation. If the temperature is too high the less the orientation achieved; if the temperature is too low uneven stretching causes thin spots and even rupture. Where the film must remain thermally stable in use, it is annealed at controlled temperature and then cooled to 'freeze' the orientation before the tension is released. This helps to overcome the tendency of the polymer to return to its natural, more random molecular arrangement when heat is applied.

Biaxial orientation has the following effects on the properties of a film:

- improved moisture barrier
- improved gas barrier
- improved tear resistance
- improved mechanical properties such as tensile strength
- impaired heat-sealing characteristics.

Most films produced using cast extrusion are coextruded or coated films, especially where coefficient of friction, barrier and heat seal are important. Using a coating or polymer layer with a lower heat seal temperature than the main film means that the resultant multilayer film can be heat sealed without melting the main substrate (Fig. 14.7).

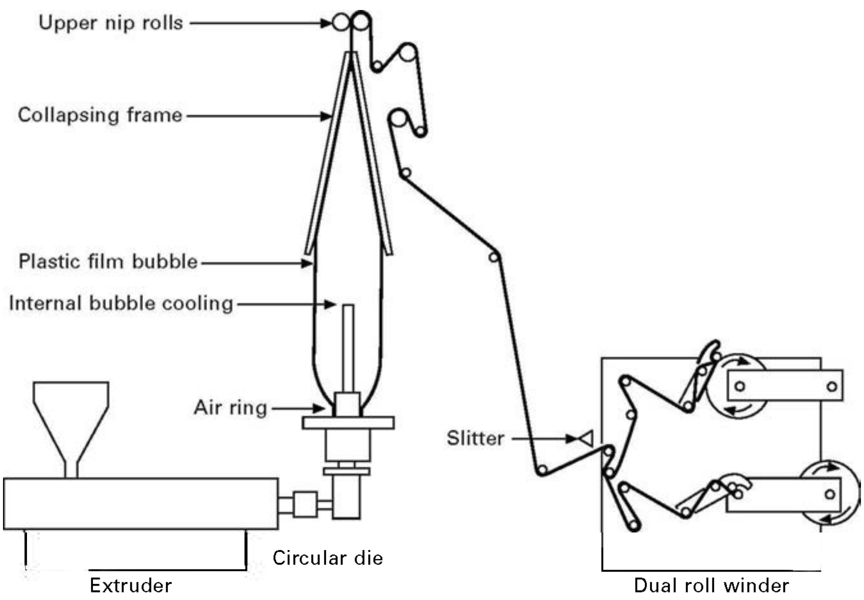


14.7 Coated overwrap film for tobacco packaging (shrink properties can be added to ensure a tight overwrap of the carton).

14.3.2 Blown film

Blown film, for all but polypropylene homopolymer (which is easier to blow downwards – see later), is routinely carried out by forming a bubble vertically upwards, as shown in Fig. 14.8. From the plasticating extruder, the molten polymer enters the annular die and is formed into a tube of material. This tube is taken up to the nip rollers where it is sealed, then air is introduced inside the tube to inflate it, creating a bubble. The inflation of the bubble increases its diameter thus orientating the film in the cross or transverse direction. The greater the ratio of the diameter of the bubble to the diameter of the annular die, the greater the orientation. This is known as the 'blow up ratio' or 'blow ratio', which is determined by the melt strength of the polymer; the greater the strength the higher the blow ratio that can be used.

Chilled air is blown on the outside of the film to cool the polymer bubble below its melting temperature T_m. The frost line is the point at which crystallisation occurs as the melt solidifies; as a result some transparency is lost. It is important therefore



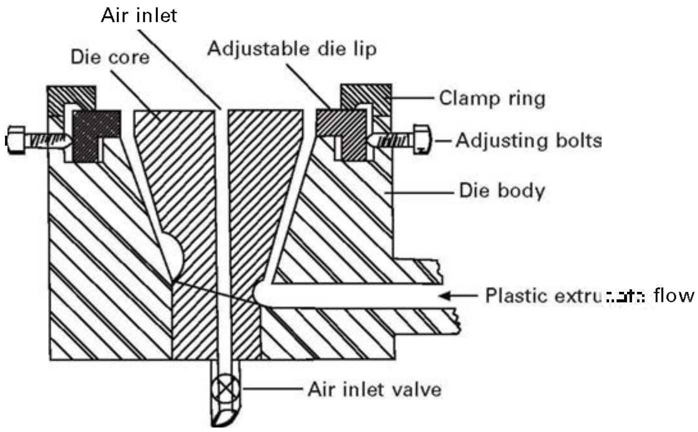
14.8 Standard blown-film process.

that the cooling speed is controlled carefully, to manage the change from liquid to solid state. The slower the film is cooled, the larger the crystals formed, resulting in less transparency and gloss of the resulting film. Some extruders employ internal cooling to increase production rates. The external and internal cooling air is normally refrigerated to allow for better control of the final properties of the film.

To achieve machine direction (MD) orientation, the film is stretched in the longitudinal direction by drawing it through the nip rolls at a faster rate than it is coming out of the die. The final thickness is controlled by the die gap and the amount of orientation imparted to the film. Orientation in both directions takes place while the polymer is still molten (Fig. 14.9).

It is important to control the symmetry of the bubble, i.e. the area of film on both sides of the centre line must be equal. If the film is uneven in either thickness or solidification, the bubble will be asymmetrical and the thicker side of the bubble will not expand as much as the thinner side, thus the gauge of the film will be uneven across the web. Also, as the thinner side will expand to a greater extent than the thicker side, it is possible that this will lead to excessive thinning and the bubble will burst. Certain parts of the film have high spots caused by imperfections in the process. These are often in the same place across the web of the film and when it is wound up these high spots can multiply, resulting in a ridge in the finished roll of film. To prevent this happening either the die, or more commonly with mono films the bubble frame and nip, are rotated to and fro (oscillated) to evenly distribute the high ridge, greatly reducing any adverse effects.

Once cooled the film approaches the nip roll and the bubble is gradually flattened into what is known as lay flat tubing. The nip rolls, one metal and one rubber transport the film to the in-line slitters and roll winders at the base of the line (see Fig. 14.8).



14.9 Cross-section of an annular blown-film die.

The slitting of the film can be carried out off-line if a high level of dimensional accuracy in slit width variation is required. When very wide films are required (e.g. agricultural film) the lay flat tube is slit on one side only, to allow the film to be opened out to its full circumference in use.

The bubble film method is used mainly to produce monolayer or co-extruded polyolefin films, used for stretch and shrink wrap materials. Stretch wrap is used to hold pallet loads of transit packaging in place. It works because when stretched, the polymer molecules want to return to their original formation, providing the elastic limit has not been exceeded. Most stretch films are made from modified LLDPE. EVA blends and plasticised PVC are also used. Coextrusions are produced to add cling features to one or both sides of the film. Ideally stretch film should have:

- a smooth surface to improve cling
- good elasticity (elongation and recovery)
- transparency (some special films are opaque)
- high tensile strength in the machine direction (MD)
- high fatigue resistance (relaxation with time)
- low creep properties
- good puncture resistance
- good tear resistance
- low neck-in properties (reduction in film width when stretched).

Some stretch wrap used for wrapping pallets (especially in the brewing industry) is perforated to allow the free flow of air through the pallet, reducing the effects of condensation.

Shrink wrap also relies on a film's tendency to want to return to its unstressed state. Shrink wrap relies on the in-built stresses in the film being stable until heat energy is applied. This allows for the shrink wrap to be loosely applied to the pack and heat sealed into a loop. It is only when heat is applied to the film that it shrinks tightly around the pack, holding the contents in place.

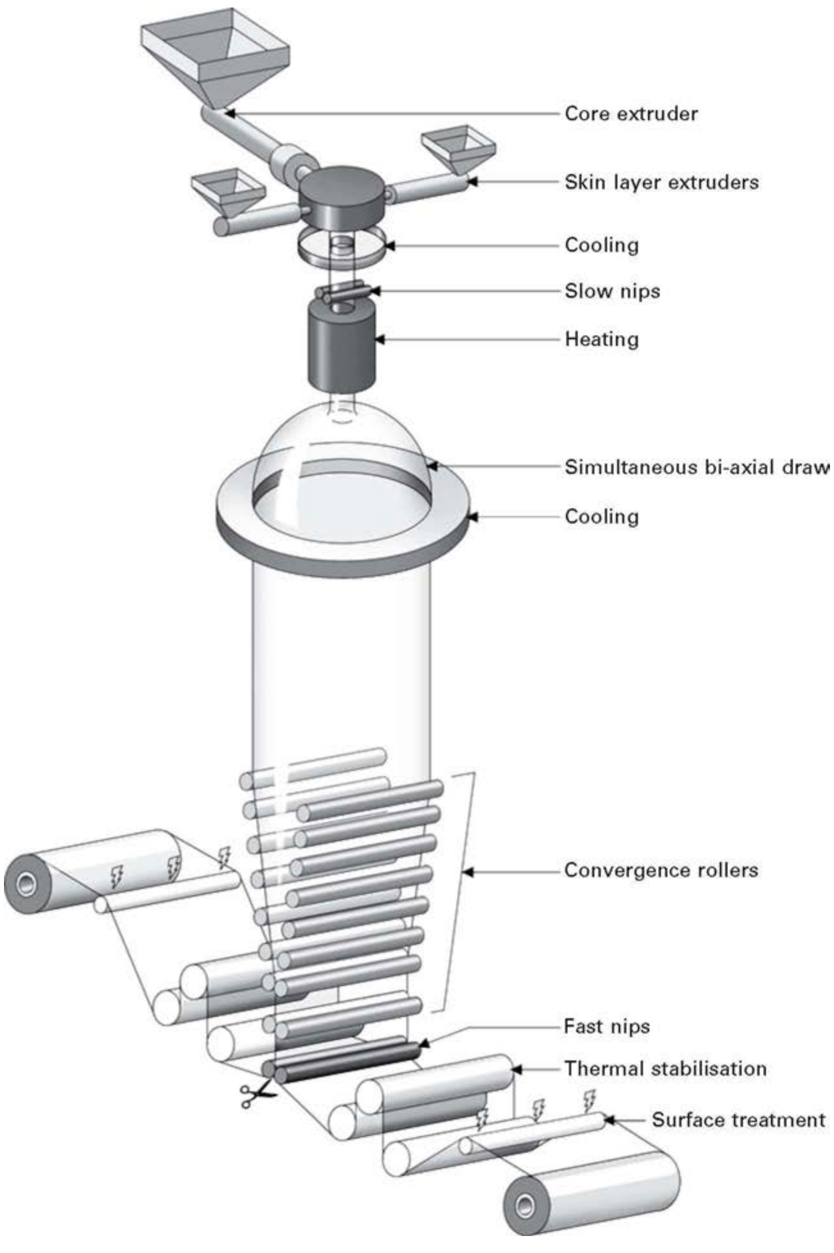
Shrink film is made by orientating the bubble in both directions and then freezing the stressed molecules by freezing the film as quickly as possible. When heated the in-built stresses are released and the film shrinks. Lightly crosslinked materials with elastomeric properties are often used to increase the shrink properties of the film. Shrink wrap is made from a variety of polymers, including LDPE, LLDPE, PP copolymer and PVC. The properties required from shrink film are similar to those required for stretch film:

- transparent (some special films are opaque or all over printed)
- controlled shrink ratio is both directions
- good puncture resistance
- good heat-seal characteristics
- appropriate slip characteristics
- low creep properties
- high fatigue resistance
- good tensile strength.

While polypropylene copolymer films can be made using the blown process described so far, as already mentioned polypropylene homopolymer has low melt strength and a better approach is to blow vertically downwards as shown in Fig. 14.10. Molten polymer travels to the annular die as already described, but instead of being immediately blown, it is formed into a cast tube which runs vertically downwards. This tube is then reheated to its softening point and inflated to form a large transparent bubble, which effectively orientates the material equally in both directions. The bubble is then collapsed and two knives are used to slit the film into two webs. These are annealed to reduce their tendency to shrink and may also be surface treated to improve print adhesion (as discussed in Chapter 12). BOPP film produced in this way is very similar in properties to cast BOPP already discussed and competes in the same markets. BOPP PP film has many uses, from overwrap for cigarette packets and chocolate boxes to FFS packaging for fresh produce and in its coated and laminated form, bags for potato chips (crisps).

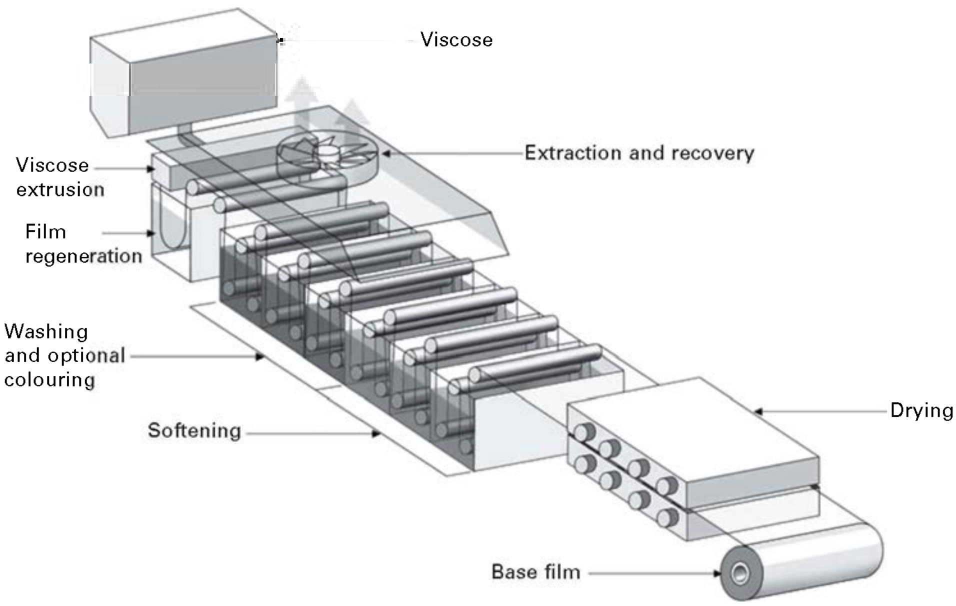
14.3.3 Cellulose film

There is one other transparent film type used in packaging which was the forerunner of BOPP. That is cast regenerated cellulose (Cellophane™ and much more recently the biocompostable regenerated cellulose film NatureFlex™). As it is not made from oil, but from cellulose fibre, it is neither thermoplastic nor thermosetting and is not a true plastic. However, it is a useful packaging film. Wood pulp produced by the chemical process (see Chapter 10) is chemically converted into a thick liquid form called viscose, which is extruded through a flat die into a regeneration bath (Fig. 14.11). At this point the viscose converts into a solid thin film form. Many processes incorporate two dies on the same machine, allowing the manufacturer to double output on the same casting machine. The web is carried down the casting machine on rollers, through a series of baths which wash and soften the film in order to produce a kind of 'transparent paper'. At this stage the film is transparent and glossy but has no heat seal and moisture barrier as one would expect from cellulose. In most cases,



14.10 The 'bubble' process for producing biaxially-oriented polypropylene (BOPP) (courtesy of Innovia Films, www.innoviafilms.com).

an anchor resin is applied in the final bath, prior to drying, to prime the surface to make it receptive to secondary coatings applied off-line. The secondary coatings are tailored to provide the heat seal and barrier properties for the intended use, (e.g., PVdC (polyvinylidene chloride) to provide a heat seal, gas and moisture barrier).



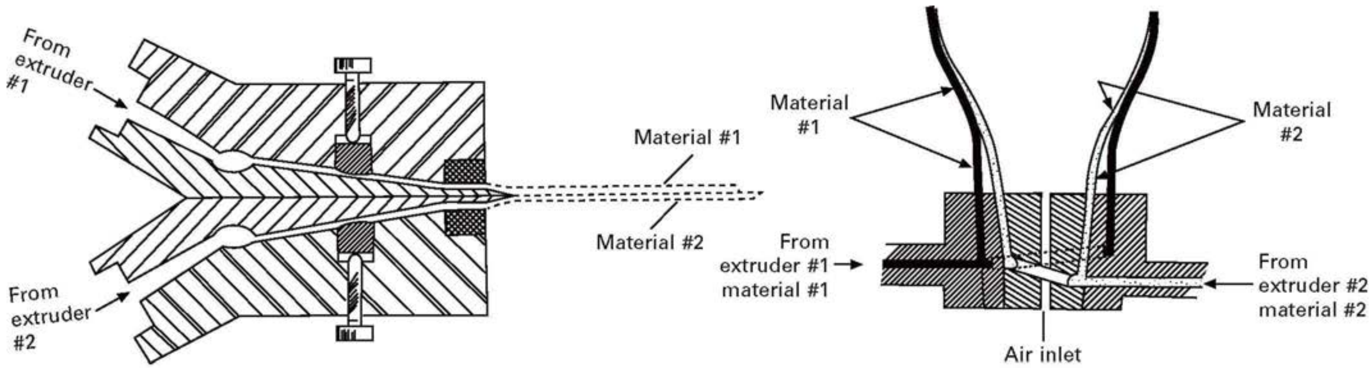
14.11 The casting process for producing regenerated cellulose film (courtesy of Innovia Films, www.innoviafilms.com).

14.3.4 Coextrusion of cast and blown films

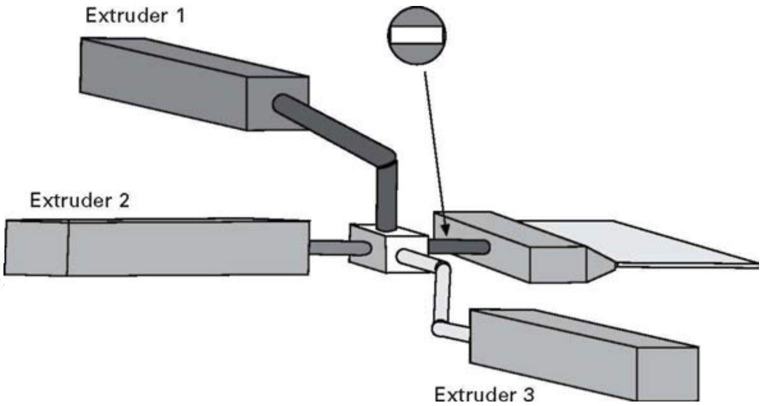
Coextrusion is the process used to combine two or more different polymers during the extrusion process. The use of three layers is common but more than nine is possible to achieve a variety of functional benefits by careful choice of each layer. Aesthetic effects such as coloured layers and layers with coloured stripes can also be achieved. The combining takes place while the polymers are in the molten state, just before the extrusion die in the cast process and just after the extrusion die in the blown film process. This allows the different polymer layers to bond together, without mixing, to form a laminar structure. The purpose of using this technique is to maximise the properties of polymers at optimum cost (see Fig. 14.12). Coextrusion can also be used to produce cast sheet, as explained earlier, with coloured stripes or layers as well as sheet for thermoforming containing barrier layers such as EVOH.

Each polymer type requires its own extruder. All the extruders feed into an adapter, known as the feed box, before entering the die or directly into the multi-manifold coextrusion die (Fig. 14.13). In the cast process the individual extruders connect with the feed box, where the polymers combine in layers. This permits a simpler die design. However, multi-manifold dies (as used for blown film) are used where the flow properties of the polymers are widely different. The multi-manifold system provides a shorter flow path before the polymers solidify and therefore less chance for distortion at the interlayer interface.

When some materials are combined together (e.g., HDPE and PA or PP copolymer and EVOH), their adhesion to each other is very weak, which would result in delamination during subsequent conversion processes such as printing or bag making.



14.12 Coextrusion processes: slot cast coextrusion die (left) and annular blown film coextrusion die (right).



14.13 Cast film coextruders feeding into the feed box and die.

To overcome this, a third component has to be added, to act as a tie or adhesive layer. As mentioned previously, this means the use of an additional extruder for every tie layer. Processing of the coextruded film is the same as for the monofilm, described earlier. Once films are reeled, they often have to be left for 48 h for the molecular structure and slip additives to stabilise before proceeding to the conversion stage.

14.3.5 Performance parameters of polymeric films which require strict control

Packaging films require control of many performance parameters to ensure that there is consistency throughout conversion and use of the film. The main areas which must be specified are listed below:

- *Thickness*: Control of thickness is very important for ensuring consistency of heat sealing, printing and mechanical strength. Thickness of film is difficult to measure by hand as individual points will vary considerably. It is therefore important to take a number of measurements over a small area using a micrometer with a 25 mm head, and to average the results.
- *Basis weight*: Basis weight, also known as grammage is an alternative to thickness as a way of controlling film.
- *Density*: Once thickness and basis weight are known, the yield can be determined, i.e. the number of square metres that can be obtained for 1 kg of polymer.
- *Moisture barrier*: Where appropriate, moisture vapour transmission rate (MVTR, also known as water vapour transmission rate, WVTR) needs to be accurately measured at a predetermined temperature and humidity.
- *Gas barrier*: Where appropriate, gas barrier (e.g., oxygen, carbon dioxide, nitrogen) needs to be measured at a known temperature and humidity. Separate measurements need to be taken for each individual gas.
- *Grease barrier*: Not all polymers have a grease barrier that is required for high fat content products, such as butter and dry pet foods. The type of fat is also

important. There are several test methods which usually reflect the actual filling and storage conditions using the product provided. Where this is not possible, tests are carried out with chemicals selected to provide a guide to the barrier properties of the particular film.

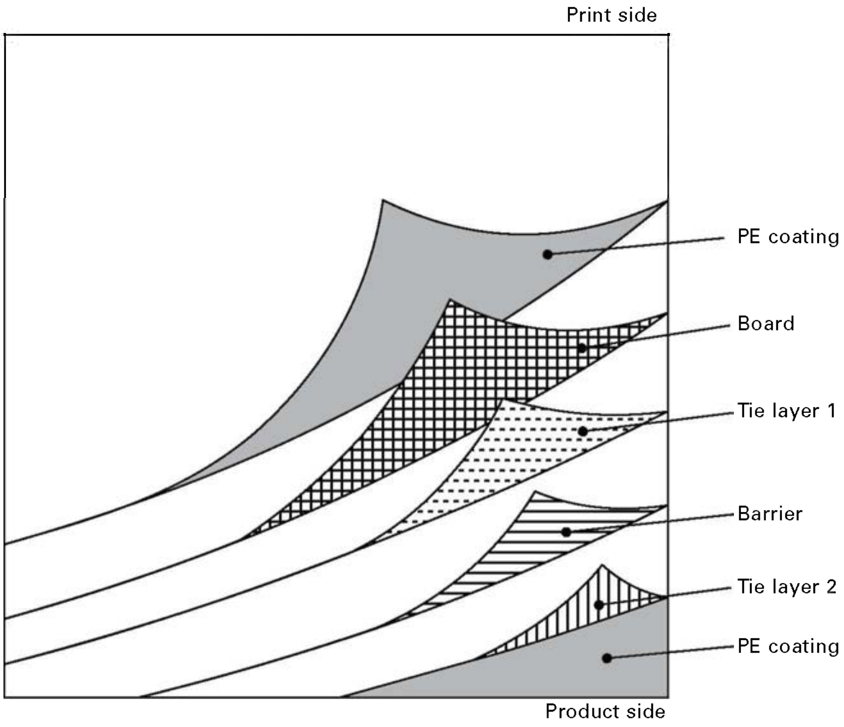
- *Coefficient of friction (CoF)*: Coefficient of friction is the reciprocal of slip. The more slippery a surface is, the lower is, the coefficient. There are two types of test. One uses an inclined plane where the angle is altered until the sample slides. The second and far more accurate method uses a moving sled on a flat bed. This method is used to determine both the static (CoF at the point the sled starts to move) and the dynamic (CoF as the sled is moved) at a constant rate under controlled conditions of temperature and pressure. It is very important to have a constant CoF within a film, otherwise it will not move over packaging machinery smoothly, having a negative effect on the line efficiency.
- *Heat-seal temperature*: Polymer films are complicated, ranging from films made up of one or many monomers having varying properties to films that are coextruded, laminated or coated with other polymers. The ideal film for heat sealing is one where the outer part of the film has a significantly higher sealing temperature than the inner, and the inner part of the film has a very wide sealing range. To ensure the correct film is selected and that the heat-sealing characteristics are uniform throughout the web, tests are carried out where the temperature, dwell time and pressure are varied to determine the ideal sealing conditions.
- *Cold-seal strength*: Sometimes, for example when packaging a chocolate bar, a cold-seal adhesive is used. The same type of test is carried out as for heat seal to ensure consistency of performance.
- *Tensile strength and elongation at break*: Tensile strength determines how much force is required to break the film of a given thickness and the elongation determines how much it will stretch before it breaks. Both these parameters are important especially for a printed film. The film has to pass through the tensioning rollers of the packaging machine without breaking or distorting the print.
- *Stiffness*: Stiffness of films is very important when making bags, sachets and pouches which need to stand up without sagging. It is also important when placing a bag into a carton. The thicker the material the greater the stiffness but the higher the cost; therefore for many applications stiffness at lowest thickness is a very important attribute.
- *Puncture resistance*: Plastic films are used to pack many items which have sharp edges. If the puncture resistance is too low then the product will place a hole in the film thus significantly reducing any barrier which has been engineered into it.
- *Surface energy*: Polyolefins have a poor surface energy which results in print and adhesive not bonding to the surface of the film. To overcome this, the surface is activated by corona discharge, flame treatment or application of a special coating. This increases the surface energy to about 42 dynes/cm which is sufficient to ensure the surface print or adhesive keys to it.

Other characteristics of the film may also be tested. These would include gloss, haze, optical density, anti-fog, anti-blocking and direct food contact. There are other market specific tests which need to be carried out, such as:

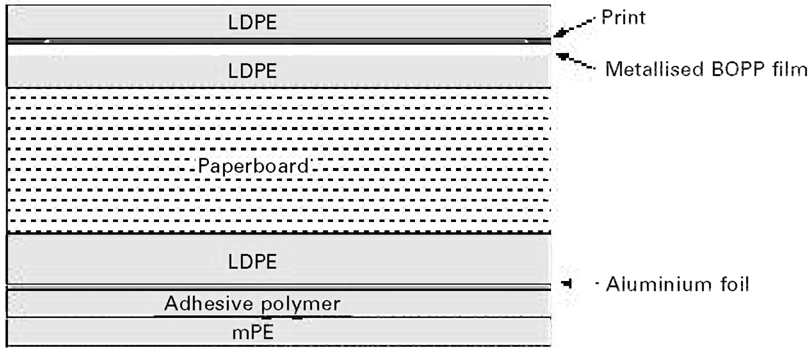
- reel geometry – accuracy of slitting and reeling – edges parallel
- which way wound? – side A or side B on the outside
- how palletised? – care of edges and flattening of the reel – reels of film should be stored and transported suspended between A frames or for less critical films (e.g., stretch and shrink) on their ends with or without edge protection.

14.4 Film treatments after forming

Coextruded, laminated, coated or single material flexible packaging can be found in thousands of different specifications, specially developed to suit the needs of the product, machinery, distribution chain, aesthetic, convenience and environmental considerations. Examples are shown in Figs 14.14, 14.15 and 14.16. Films can, for example, be given special treatments or coated to improve their properties. Examples include corona discharge to improve surface adhesion and vacuum deposition of mineral oxide, metal oxide or metal particles (Fig. 14.17). Films are treated with a vacuum deposition to improve aesthetic and barrier properties. Aluminium is the



14.14 Example of a typical packaging laminate (courtesy of Elopak; www.elopak.com).



14.15 Example of a laminate for a carton containing liquid (courtesy of Tetra Pak; www.tetrapak.com).

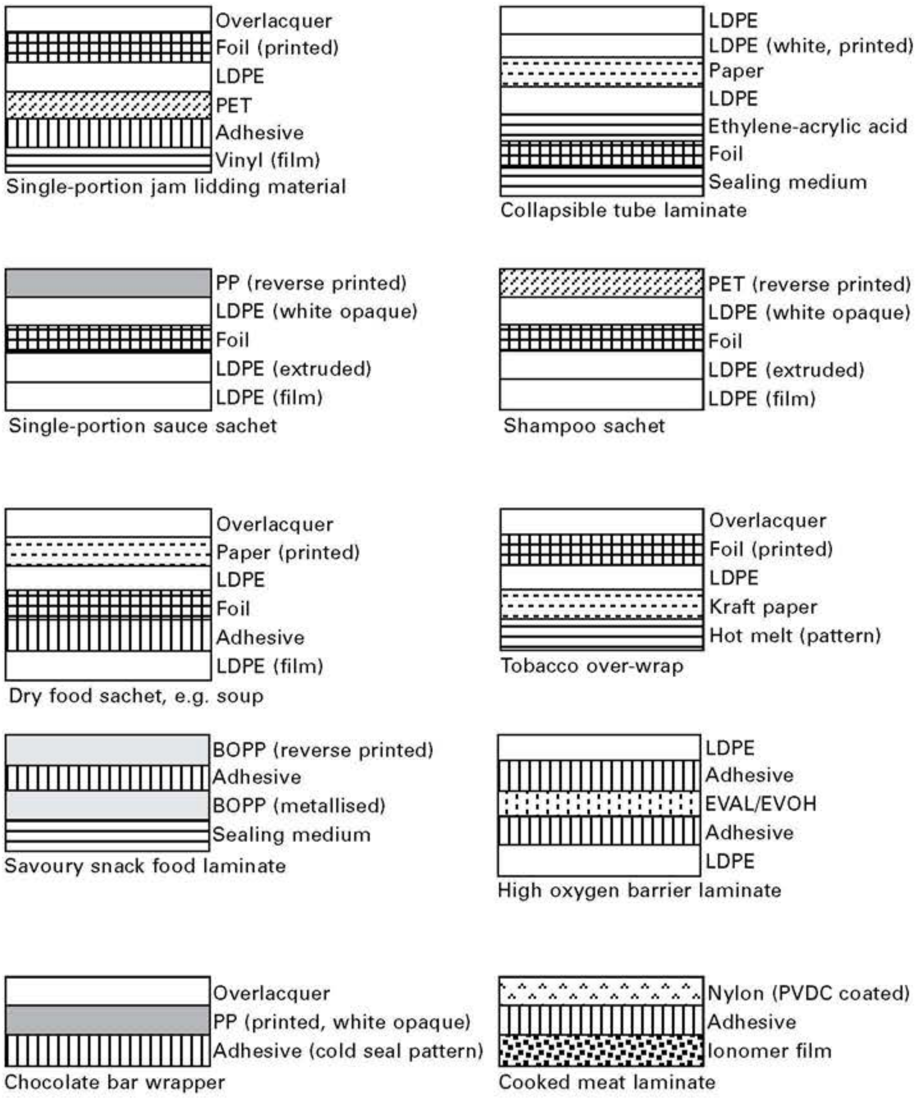
most common vacuum deposition material used in packaging, providing a very bright silvery surface improving the UV, gas and moisture barrier of the film. Aluminium oxide and silicon oxide are also used where clarity is important, but improvement of gas and moisture barrier is still necessary. The two main films metallised are PET and PP copolymer. The new biocompostable films (e.g., PLA) are now being treated by vacuum deposition in an attempt to improve moisture barrier.

14.4.1 Lamination and coating of flexible materials

As already discussed, it is possible to combine polymers using coextrusion, but this is not always practical, for example for short-run lengths of specialised materials. Also, it is not possible to include layers such as aluminium, paper and paperboard in coextrusions. Lamination processes may be required, in which webs of individual materials are combined using adhesives (Fig. 14.18).

The simplest laminate is paper or paperboard extrusion coated with a polymer on one or both sides. Polymer granules are placed in the extruder where they melt and pass through a slot die. The extruded film width and thickness are controlled by the die and the speed of application of the plastic to the substrate. The melt is at such a temperature that it will adhere to the substrate after which time it is passed over a chill roll which cools the melt prior to it being wound up into a reel. If both sides of the substrate are to be coated, the procedure is repeated or another extruder is situated in line with the first. This process addresses some of the inadequacies of the base material and typical end uses include ream wrap, sandwich cartons, frozen food, pet food and soap powder bags, sacks and cartons. The polymers normally used are PE, PP and PET. Hot melt adhesives are also applied in this way or via a roller application (Fig. 14.19).

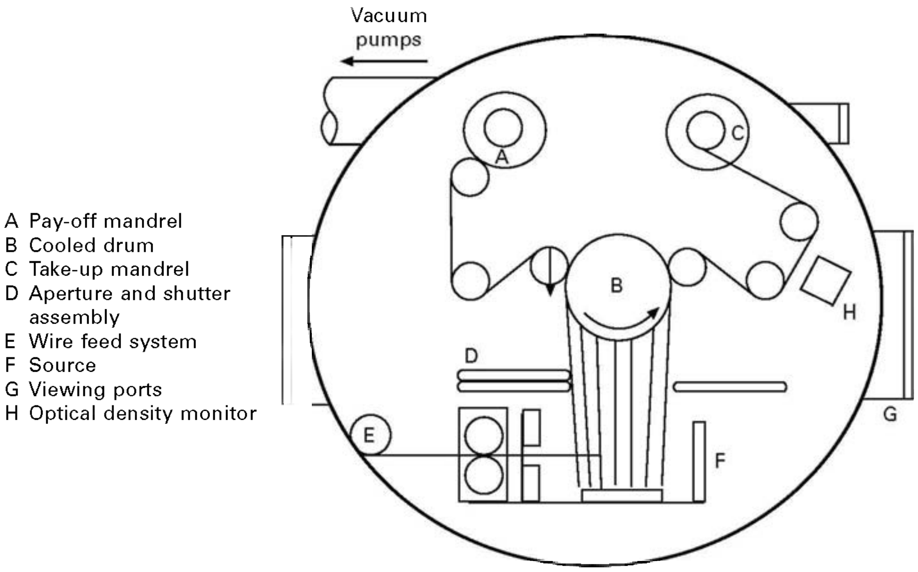
More complicated extrusion coated/laminated structures are used for liquid packaging cartons. Here two or more extrusion heads are used to produce a laminate of plastic/paper/plastic/aluminium/plastic. The paper gives rigidity and a good printing surface, the aluminium provides barrier to UV, oxygen and moisture vapour



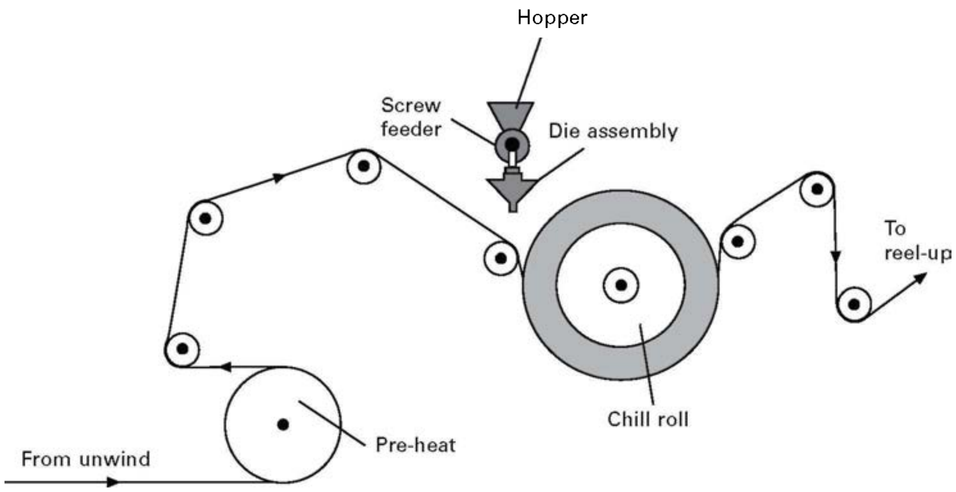
14.16 Examples of laminates for specific product applications.

and the plastic seals the surfaces together. The plastic also provides an external barrier to condensation and an internal barrier to product penetration into the paper.

In addition to extrusion lamination, other laminating techniques which can be used, depending on the combination required and the end use, are dry bond lamination and wet bond lamination. Dry lamination can be achieved by a variety of means. The oldest is probably wax bond lamination (Fig. 14.20). This will bond substrates together but as it is a non-polar material, it relies mainly on mechanical bonds, for example to paper, but can achieve moderate chemical bonds to aluminium and plastic

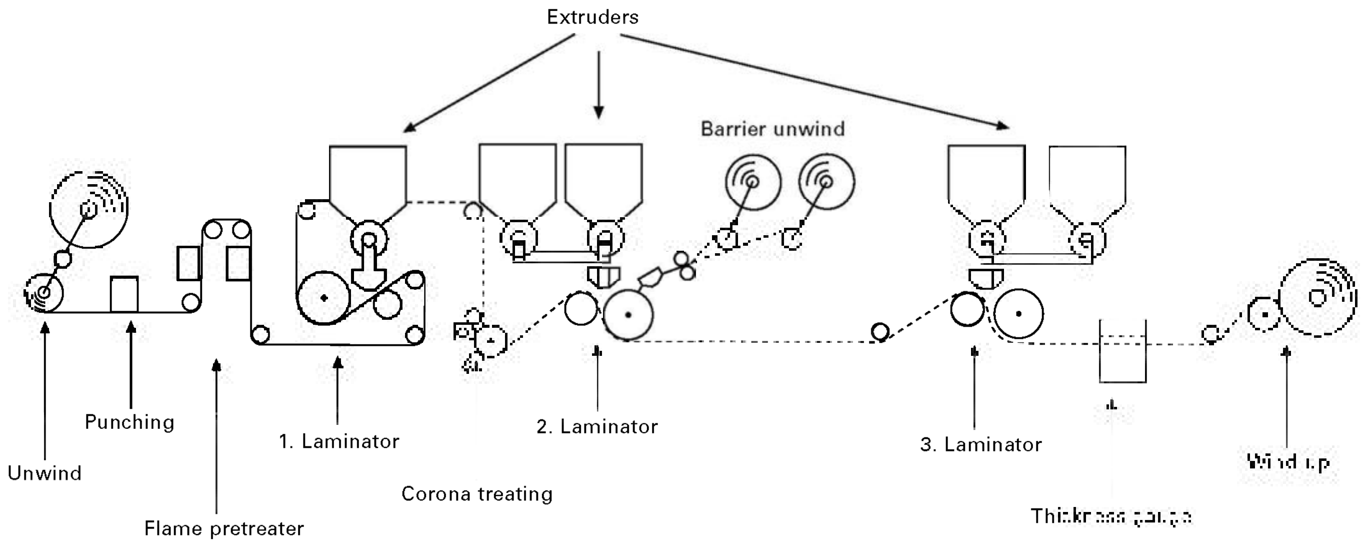


14.17 Film metallising chamber.

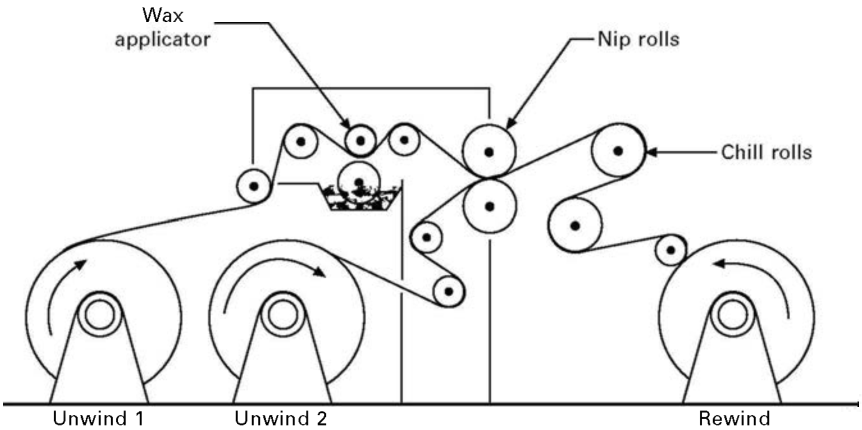


14.18 Extrusion coating process (courtesy of Walki Group; www.walki.com).

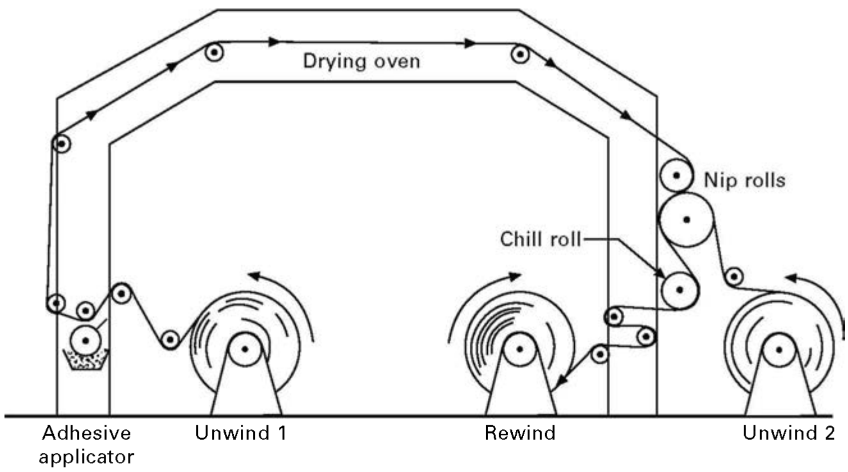
substrates. The wax is applied molten to the substrate via a wheel applicator; whilst the wax is still molten a second substrate is applied to the wax coating on the first and the whole is bonded by passing through a nip roller and cooled via a chill roller immediately prior to being reeled up. One of its most common uses is in lamination of foil to paper in the wadded closure used for jars of coffee. The laminated wad in the closure is induction sealed to the top of the glass jar. The heat generated melts the wax which is absorbed into the paper. When the jar closure is unscrewed the wax



14.19 Process for coating both sides of a substrate (courtesy of Elopak; www.elopak.com).



14.20 Wax bond laminator.



14.21 Dry bond laminator.

bond breaks leaving the paper wad in the closure and the aluminium foil diaphragm sealed to the jar.

Dry bond adhesion is very useful when two non-porous materials need to be laminated (Fig. 14.21). Water- or organic solvent-based adhesives are applied to one surface, and the solvent is driven off in a heated oven. The hot tacky adhesive-coated substrate is then laminated to a second substrate, using a nip roller which is often heated to ensure the dried coating is still active. It is important that all solvent is driven off prior to bringing the two substrates together, otherwise it is trapped between the substrates, which can have a negative effect on adhesion and also can contaminate the packed product. It is also necessary to consider the management of the volatile solvents given off in the drying process, to comply with relevant legislation.

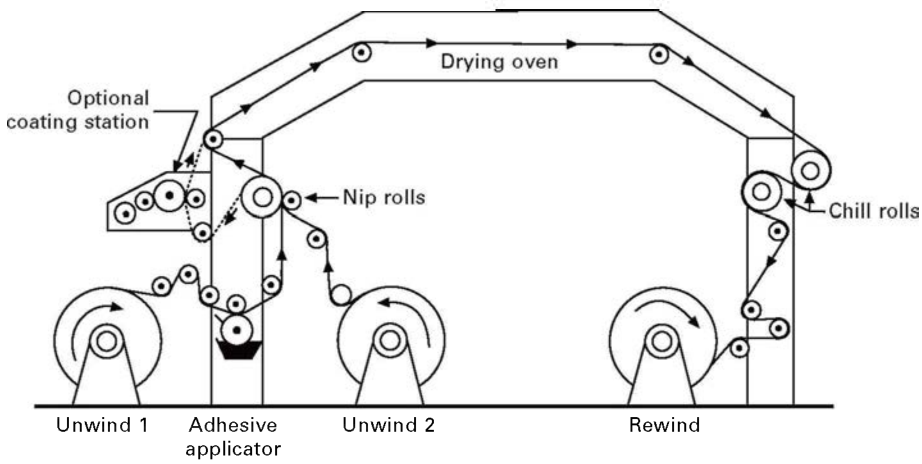
The final type of dry bond adhesion to be discussed is the use of two-part polyurethane adhesives (Fig. 14.22). These are 100% solid and therefore, as with extrusion lamination, do not require drying. They are applied to the web at ambient conditions and rely on a chemical crosslinking reaction for the bond to be completed. This can take up to 48 h before the laminate can be further converted, e.g. slit into smaller reels, otherwise delamination may occur. Once cured these adhesives have much higher temperature resistance than their thermoplastic counterparts and therefore can be found in the construction of retort pouch laminates.

Wet bond lamination is used where one of the substrates is porous (e.g., paper). The two substrates can be brought together before the oven, where the heat dries the adhesive and the substrates. Care needs to be taken during drying to ensure the moisture profile along the length and across the web of the finished laminate is stable.

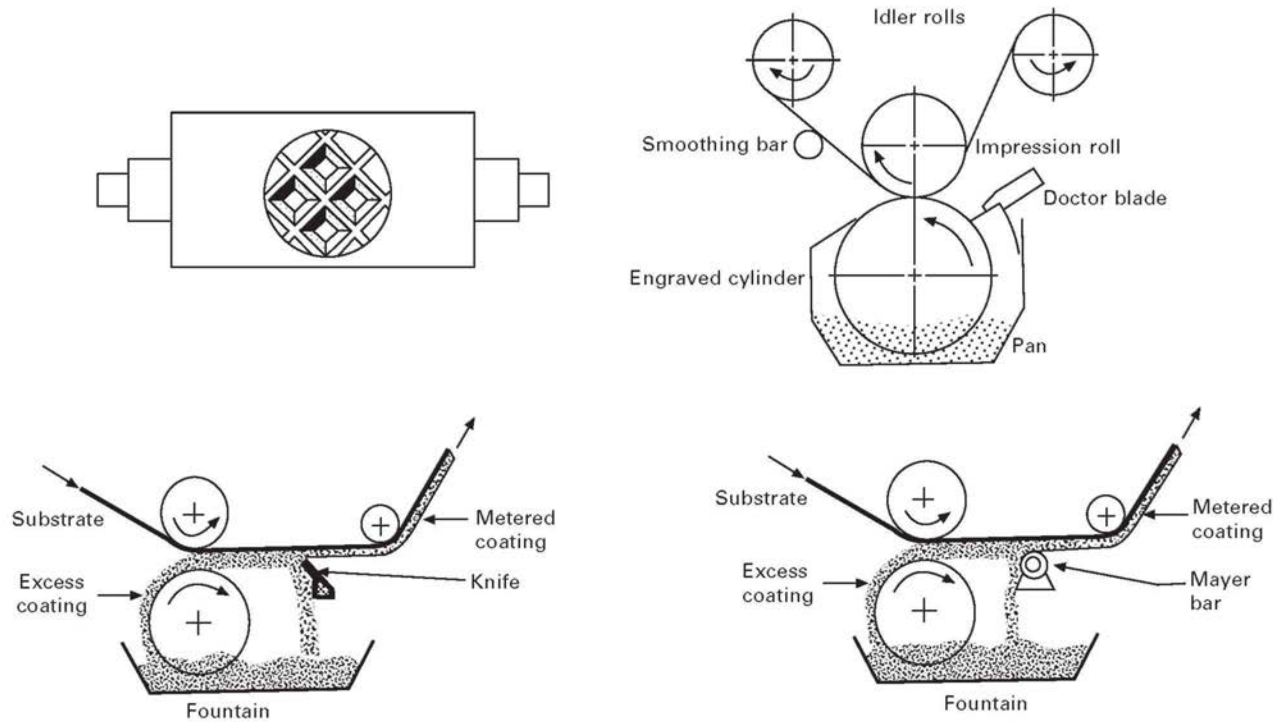
Coatings can be added to substrates during the lamination process (as with wet bond lamination), as part of the printing process (e.g., cold-seal adhesives for sealing of confectionary bars) or as a separate operation (e.g., water-based functional coatings to replace polymer films and fluorocarbons, for pet food and fresh produce). They can be added via a gravure or anilox roller, or knife or rod metering system (Fig. 14.23).

Often the board is preprinted before it is coated with polyethylene. The tie layers ensure good adhesion between incompatible substrates. The barrier layer is usually aluminium but could be ethylene vinyl alcohol (EVOH) coextrusion. In Fig. 14.15 you will notice a difference from the specifications shown in Fig. 14.14. Liquid packaging serves a vast market with products from acidic orange juice to high fat dairy goods, all requiring very different packaging performance.

From lids for single portion jam pots (replacing traditional aluminium) to collapsible tube laminates for toothpaste, film for tobacco overwrap, savoury snacks, shampoo sachets and many, many more end uses, flexible packaging can be specified to replace



14.22 Wet bond laminator.



14.23 Gravure coating process (engraved cell shown enlarged on left).

other more traditional forms of packaging. It uses minimal materials and can be formed into sachet, bag, carton, can and bottle shapes. For example, retort pouches are currently replacing metal cans, sachets and pouches with reclosable pour spouts are replacing traditional bottles, cartons are being replaced with block bottom bags with reclosable zip systems. These flexible packs rely on judicious choice of materials to meet the end use and the requirements of the packaging machinery on which they will be formed. These requirements will be covered in Chapter 20, but at this point it is important to note that all of these processes rely on the sealing properties of the packaging material being compatible with the sealing characteristics of the relevant forming machine.

14.5 Thermoforming process for making plastic packaging

Thermoformed packaging produces a less dimensionally accurate moulding and less complicated shapes are achievable (e.g., undercuts) but is often quicker and less expensive to produce than an injected moulded container. In its simplest form the thermoforming process involves heating a sheet (which can be mono material, a coextrusion or a laminate) of even thickness and drawing it over, or into a mould to form a rigid or semi-rigid shape. The excess material is trimmed off usually, leaving a rim around the finished article. The greater the depth of the object to be formed, the more likely it is that the material will thin, even to the point of breakage, and this is one of the most serious disadvantages of this relatively simple process. This unwanted thinning can be reduced by various means as will be mentioned below.

The thermoforming process is used to make many different packaging articles, for example, tubs, pots, display trays and blister packs, and can be broken down into seven basic steps:

1. Making the sheet – normally by the cast extrusion method.
2. Heating the sheet.
3. Forming the pack by stretching the sheet either into or over a mould.
4. Cooling the formed packaging.
5. Cutting and trimming the multi-unit moulded sheet into individual units. This can be carried out at the same time as the forming process.
6. Printing or decorating as required.
7. Stacking the individual units before packing and labelling for despatch to the customer.

As with all processes, quality control throughout is crucial.

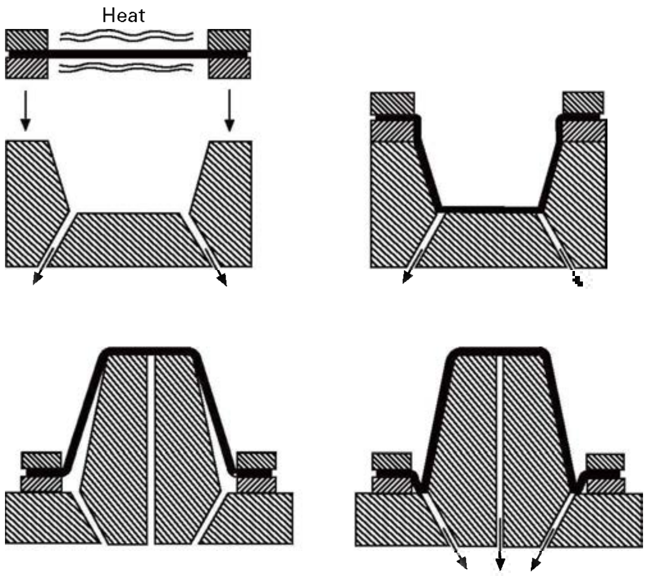
Sheet extrusion is described earlier in the chapter. The sheet can be foamed (e.g. EPS expanded polystyrene or cellular polypropylene or polyethylene) if required. As already noted, if polypropylene is being cast, it is usual to extrude the sheet in line with the thermoforming. Coextruded multilayer sheet is the most popular for thermoforming as it provides the performance and barrier characteristics required. Many packaging suppliers make the sheet and thermoform it into the required pack shape, while some packer-fillers thermoform trays from a pre-supplied reel of sheet material, place the product into it, and heat seal a flexible lid onto the tray, all on one machine.

Once the sheet is heated, the container can be formed using different methods. The traditional method was to drape the heated sheet over a cavity or plug mould, draw a vacuum and form the sheet to the shape of the mould (Fig. 14.24). This method is adequate for shallow thermoformed packaging components of uncomplicated design. If the depth is greater than the diameter then plug assist vacuum forming is the better choice (Fig. 14.25). In conventional vacuum thermoforming, the sheet is formed, the wall thins and there is a risk that the sheet will not conform well to the contour of the mould, especially in the bottom edges. Plug assist overcomes some of these inadequacies by acting as a heat sink and displacing the material in a more even manner, reducing the thinning of the wall section. This is especially useful for deep-drawn items.

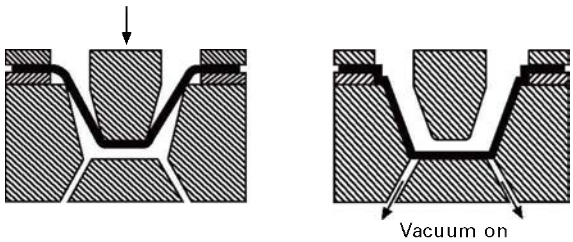
'Vacuum snap back' can also be used where overall wall thickness becomes important (Fig. 14.26). This is used for items where the depth of the article is up to 2.5 times greater than its width. The initial stretching of the sheet is free of any contact points and therefore more even than in the direct forming processes already described. As a result, the wall thickness throughout the item being formed is much more uniform. Where the depth of the article is greater than 2.5 times its width, 'billow' forming can be used (Fig. 14.27). Heat and/or pressure cause the sheet to billow upwards, a heated plug is introduced and the vacuum is turned on, forming the sheet over the mould.

Solid phase pressure forming (SPPF) has been developed to produce thermoformed articles with better definition, especially at higher pressures. The process has improved the quality of thermoformed articles to the extent that it can now compete with injection moulding for some moulding designs. It is also possible to mould two sheets, one over the other, at once. In solid phase pressure forming the sheet is reheated inside the machine until it becomes plastic and easy to form (Fig. 14.28). Using plugs and then compressed air, the sheet is pushed into the shape of the mould. It is here that by using high pressures moulding definition is greatly improved, the plug reducing the variation in wall thickness which occurs with conventional thermoforming. Once frozen, the shape is cut out of the web – this is completed while the article is still held to ensure the accuracy of the cut. The articles are ejected through the front of the machine.

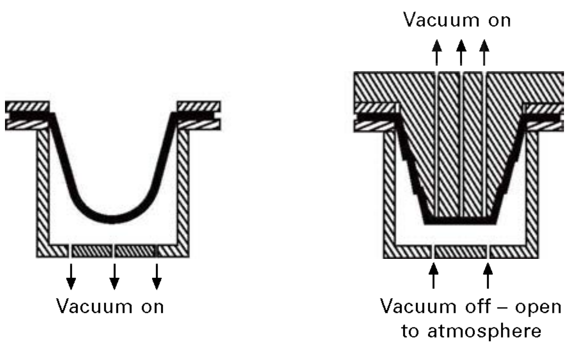
Before the moulding is removed from the mould, it must be cooled so that deformation is avoided. This is very important when thermoforming polypropylene as it has a very high shrinkage rate and, if not cooled sufficiently, it can continue shrinking for several days after it is removed from the mould. Cooling is carried out using temperature controlled water directed to cooling channels designed into the tooling. Once the article has been formed and cooled, it needs to be cut from the sheet. The cutting process leaves a rim around the article, which can be used for heat sealing and as a lip for an overcap. The forme used for cutting is similar to that used for cutting paperboard cartons. Modern developments have made it possible to minimise the lip on the article.



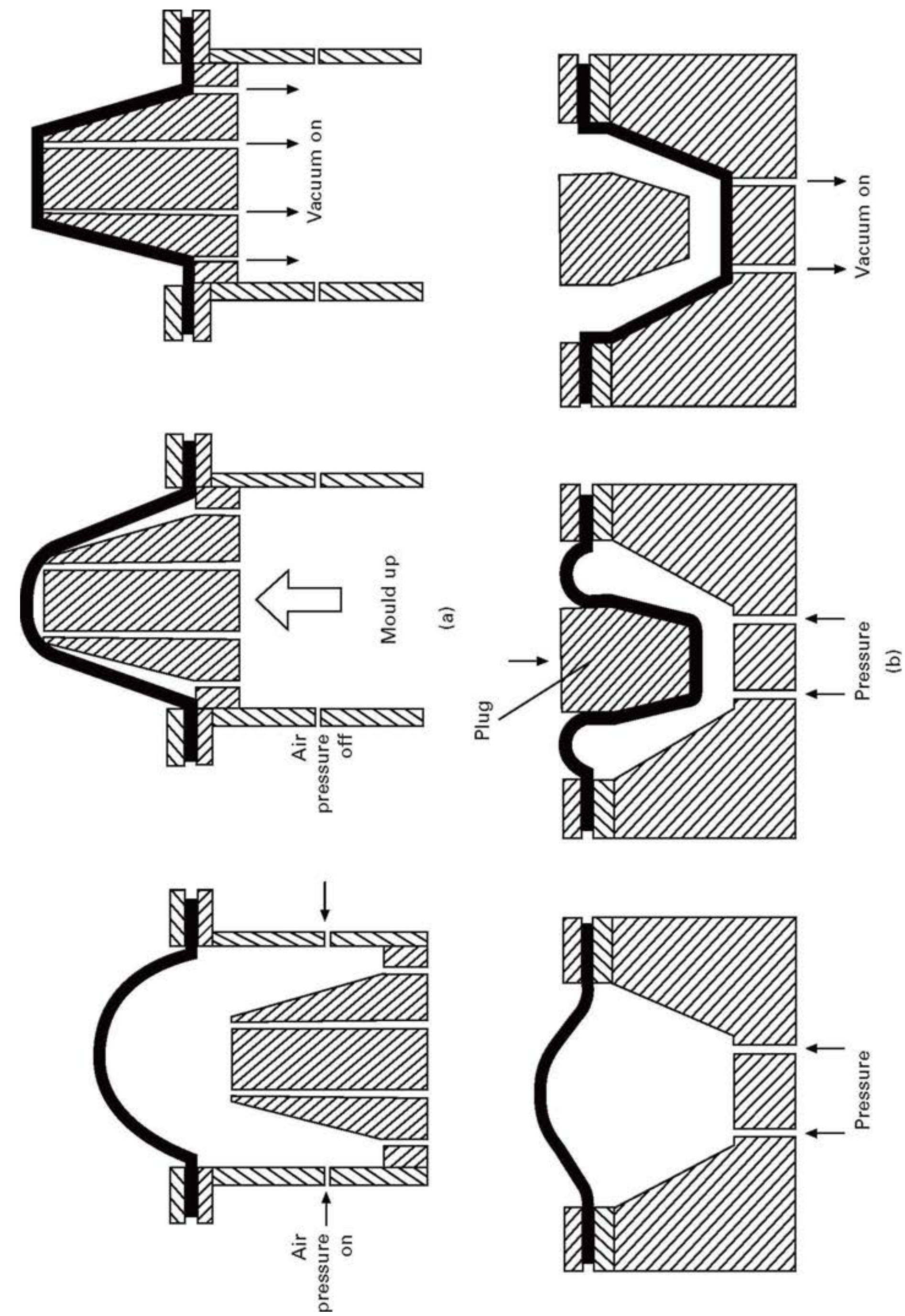
14.24 Vacuum forming over cavity and plug moulds.



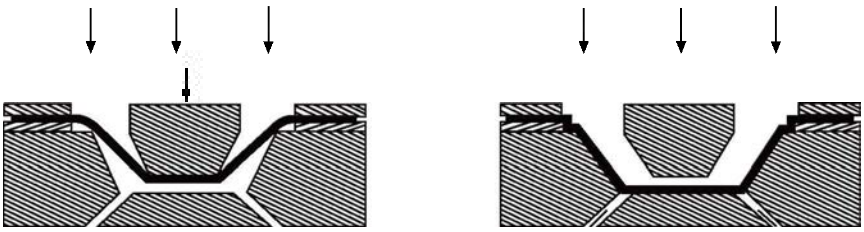
14.25 Plug assist vacuum forming.



14.26 Vacuum snap back forming.



14.27 (a) Billow forming over a plug and (b) billow forming over a cavity.



14.28 Solid phase pressure forming.

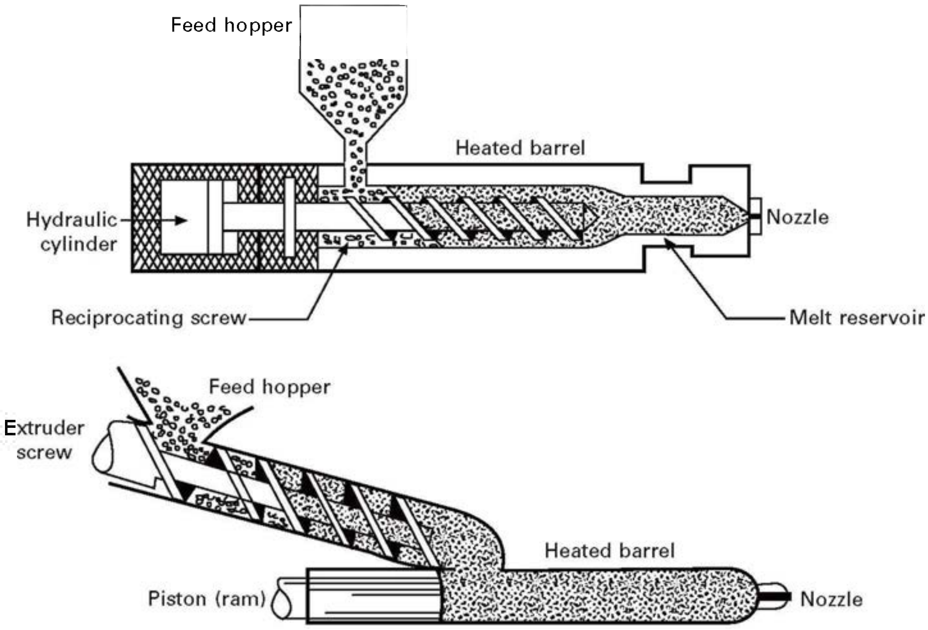
Thermoformed items can be decorated using the following methods:

- In-mould labelling – this provides the best overall graphics of all the decoration methods; however, the adhesion of the label can be adversely affected if the item is too cold.
- Dry offset (offset letterpress) and screen printing – graphics are not as good as when using in-mould labelling, although quality is improving due to modern developments.
- Colour – can be added to the extruded sheet. Multicolour stripes can be added and placed in such a way to allow one section of the item to be decorated differently from the others.
- Surface finishes – can be designed into the final thermoformed article, but the quality of finish is not as good as with injection moulded items.

14.6 Injection moulding

The injection moulding process is suitable for all materials, only the tool design having to be changed depending on the shrink characteristics of the polymer/polymer combinations. Injection moulding is a process which converts polymer granules into one of the most dimensionally accurate moulded thermoplastic parts possible. It does so using a reciprocating or ram, plasticating extruder (Fig. 14.29). Dry plastic granules are added to the plasticating extruder in the same way as described earlier in the chapter for film and sheet extrusion. Most importantly, the drying time of the polymer and its masterbatch significantly affect the process time, with PET, PA and PLA needing between 6 and 12 hours for complete drying. To overcome this problem, pre-hoppers are used to pre-dry the polymer and liquid colorant is used to negate the need to dry the masterbatch.

Once heated in the extruder, the homogeneous, molten mass is then injected into a mould through a gate, known as the injection point. A predetermined mass of polymer, designed to completely fill the mould, is metered out within the injection moulding machine, by controlling the stroke of the reciprocating screw or the ram piston. The polymer (PP has a much higher shrinkage than HDPE, for example) and the colour used significantly affect the shrinkage of the moulding. This can result in a separate die being required or changes made to the cycle time and cooling conditions used, to ensure the moulding once cooled meets its dimensional specification.

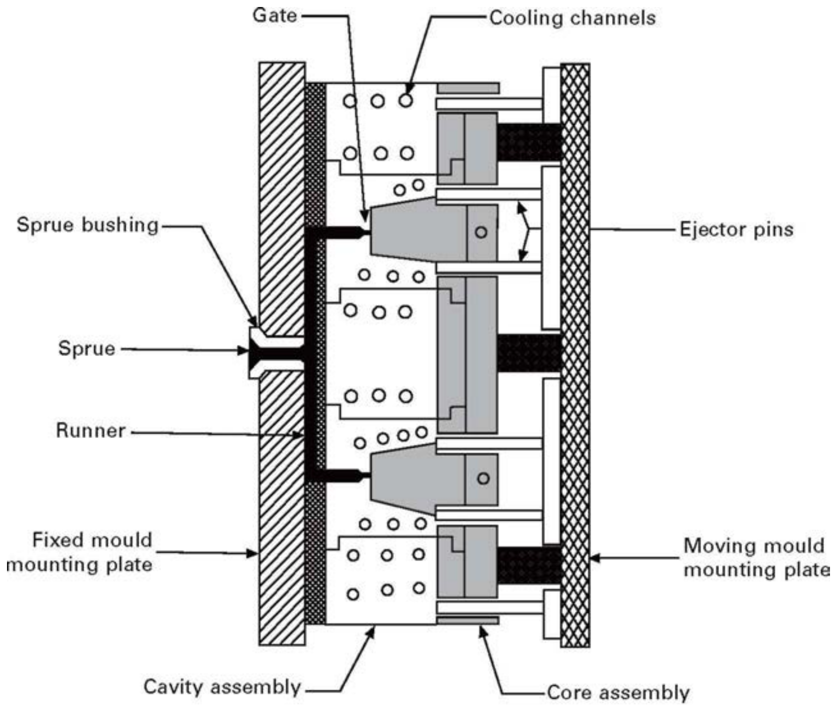


14.29 Reciprocating (top) and ram (bottom) type of injection moulding machine.

The mould consists of two or more steel parts, one with a cavity accurately cut away to form the female section of the moulding, the other with a corresponding profiled section (Fig. 14.30). When the two halves are clamped together, the gap between the male and female sections of the mould corresponds to the shape, finish and thickness of the moulding required after taking shrinkage into consideration. The parts are locked together with a clamping force sufficient to ensure that both single- and multi-cavity moulds stay closed, until the moulding is cool enough to be ejected. Multi-cavity moulds are used to increase the number of units produced over a given time and therefore reduce the unit cost. The number of cavities possible is dependent on the surface area of the cavity and the locking force of the injection moulding machine, the larger the locking force the greater the number of cavities possible.

The mould is cooled with temperature controlled liquid to ensure the mouldings cool as evenly as possible. Injection points are positioned so that the flow of material into the mould is as even and thus stress free as possible, and the whole moulding is free of weak areas where the polymer has flowed together in the mould. Injection points can be visible on the mouldings, therefore consideration must be given to this at the mould design stage. With care, they can be hidden from view (Fig. 14.31).

The injection moulding machine must have sufficient clamping force to prevent any of the injected plastic from escaping at the interface of the two halves of the mould. This would cause an unsightly part-line or excess material, known as 'flash' which has to be removed or, in severe cases, the moulding scrapped. Excessive shot size or injection pressure can also cause flash to occur, as can the use of an old, worn mould.

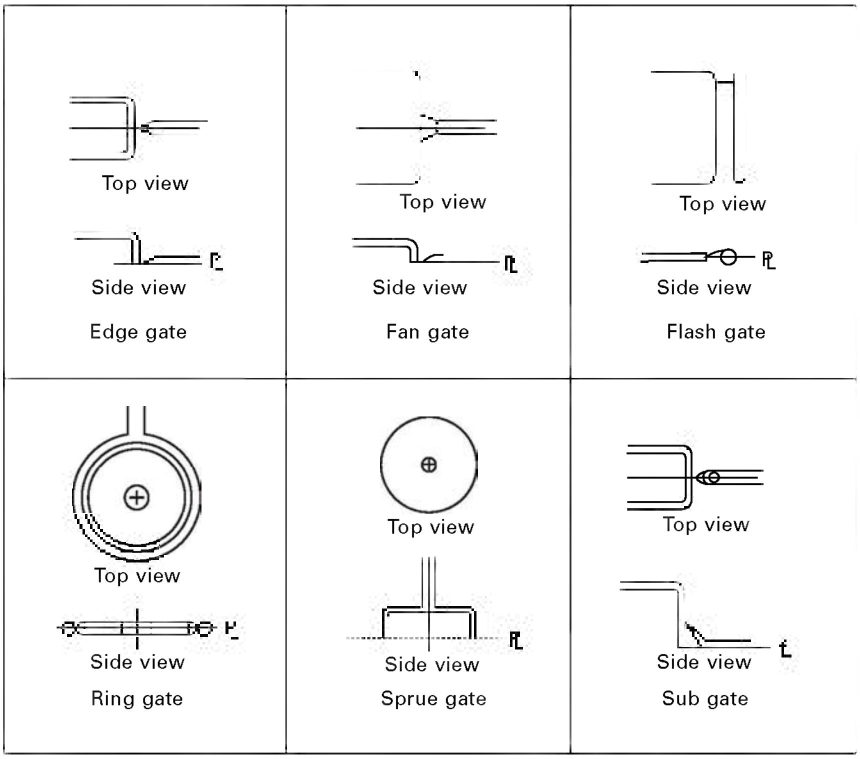


14.30 A multi-cavity mould.

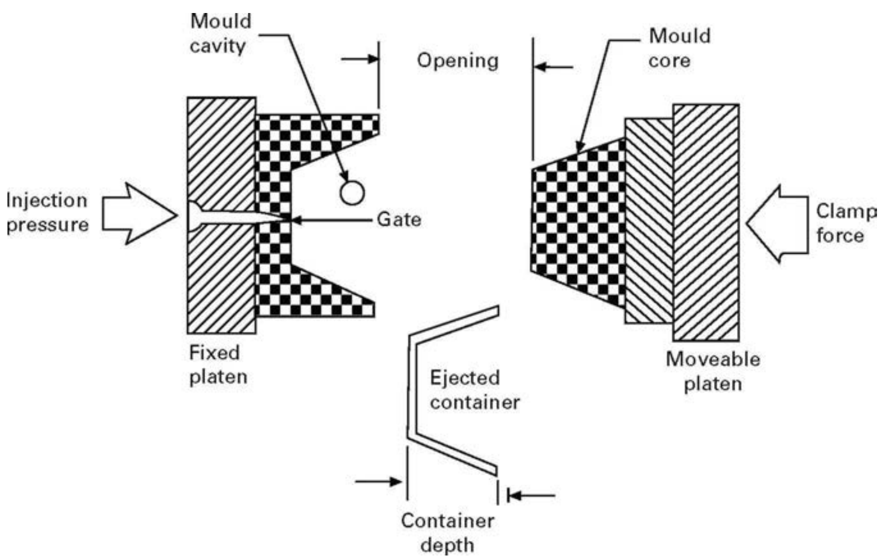
The size of the injection moulding machine is specified by its clamping force and injection capacity and the mould must be compatible with the machine (Fig. 14.32). Moulds are clamped together and opened using mechanical (toggle lock), hydraulic (direct lock), or a combination of both (lock and block or hydro-mechanical) methods. Mechanically operated machines use integrated hydraulic systems for the motive power. However, during more recent years, to improve cleanliness and reduce energy, servo-motors are used, hence the ‘all-electric’ machines. As stated, clamping forces have to withstand the internal pressure within the mould cavity, and injection pressures of around 2,000 bar (29,000 psi) are common.

Normally the female cavity side of the mould is attached to the stationary end of the injection moulding machine (fixed or nozzle platen) and the male cavity side is attached to the moving end (moving or ejector platen). The molten polymer is injected into the mould through the fixed or nozzle platen. To ensure the two halves of the mould are precisely in line (necessary to achieve accurate mouldings), large guide pins are situated on the four corners of one side of the mould with matching locating holes on the other. If moulds are not vented effectively, the injected plastic cannot displace the air inside and therefore an imperfect moulding will result. The consequences can vary from an imperfect finish on the surface of the moulding to an incomplete moulding, due to the pressure build-up in the mould preventing free flow of polymer.

Moulded parts are ejected from the mould using ejector pins, air pressure or stripper



14.31 Injection points (gates) for an injection mould.



14.32 Simple injection mould.

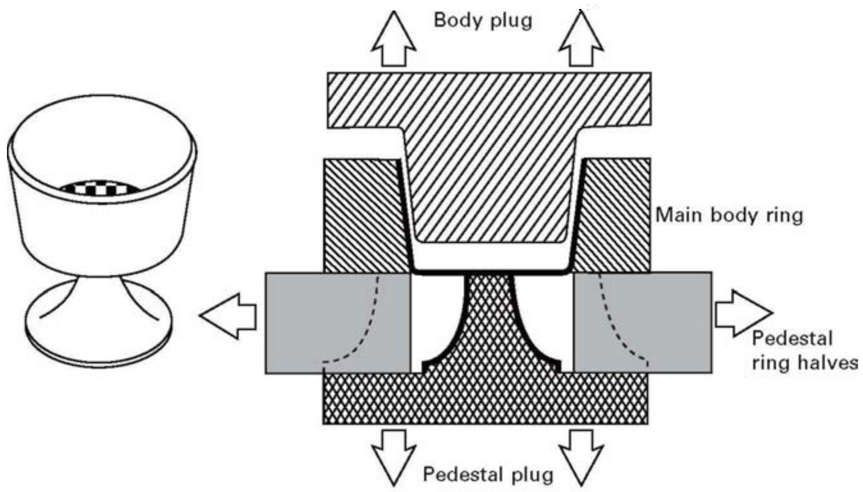
rings. The ejector pins leave a tell tale ring in the moulding, stripper rings and air pressure are much kinder in this respect. Some polymers are not tough enough to withstand the high pressures employed when using air to eject, for example polystyrene is usually too brittle. Air pressure ejection lends itself to thin section parts rather than thick.

14.6.1 Mould designs

Mould design is an important part of the development process when considering the production of a new moulding. Some considerations are given below.

- The shape of the moulded part has a direct bearing on the time involved in making the mould, the cycle time of the moulding. For example, undercuts and deep screw threads often require a separate moving part which increases the cycle time of each moulding operation.
- Angles on the side walls are necessary to ensure the moulding can be removed from the mould.
- The surface finish of the moulding needs to be decided before the mould is completed. Embossing, etching and other finishes can be added to the moulding to enhance the aesthetic qualities of the moulding. Any imperfection on the finish of the moulding will transfer to every mould made.
- Weight, surface area and thickness of the moulding directly affect cycle time. Where mouldings have significantly varying thickness, cooling has to be controlled very carefully otherwise depressions form (sink marks) on the outer surface of the moulding caused by excessive shrinkage of the thick section of the moulding.
- The number of cavities in a mould is governed by the number of units per annum required. The number of cavities directly affects the size of machine required for the multi-cavity mould; this in turn affects the cost of the mould and the unit cost of the moulding. Where there are many cavities, each one must be uniform compared to the others and the cooling profile needs to ensure that the outer and inner cavities cool at an equal rate, otherwise moulds of differing dimension will result. Hot runner systems are usually used for multi-cavity systems. This reduces the cycle time and amount of waste material formed but increases the overall cost of moulds (see Section 14.6.2).
- The need for an insert or label to be inserted during the moulding sequence has to be considered at the mould design stage.
- All injection moulds require a point or points at which the molten plastic is introduced into them. If not considered at the design stage, this can leave unsightly surface blemishes on the finished moulding which require a further stage to remove them, incurring extra costs.

Successful removal of the moulding from the mould is another critical consideration in mould design. Some mouldings, such as closures, have undercuts, which complicates the mould design. Sometimes the moulding is flexible enough, and the undercut small enough to pop or blow it off the tooling without damaging the moulding. However, this is not always the case and a more complex mould design may be required (see Fig. 14.33). Other options are the use of a collapsible core or, in the case of threaded mouldings, the incorporation of an unscrewing device.



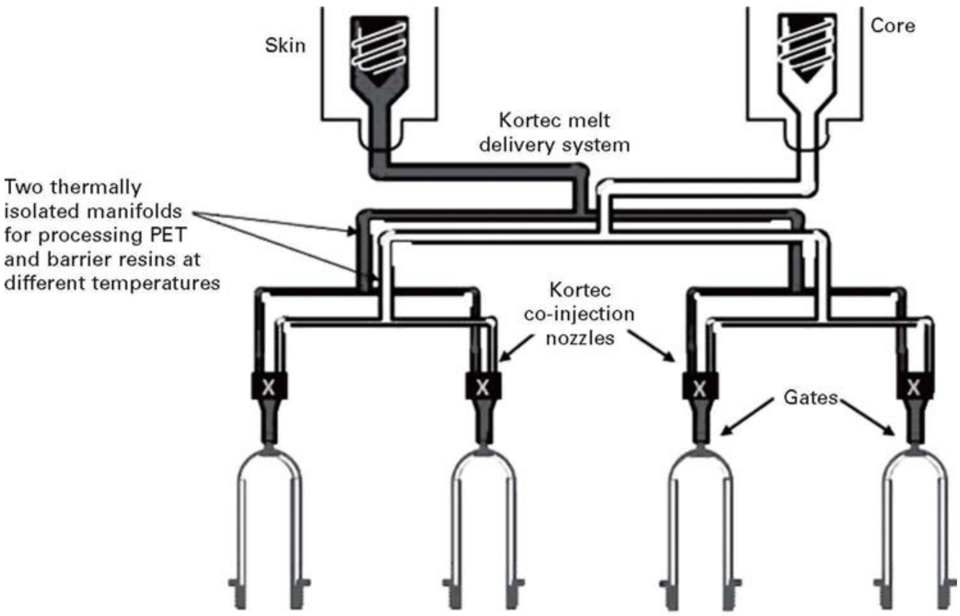
14.33 **Mould design for parts with undercuts (in this case a cup with a pedestal).**

14.6.2 Hot runner moulds

Figure 14.34 shows a hot runner mould (the figure shows a co-injection design which is discussed in more detail in Section 14.7.2). Feeding of the plastic material to the mould can be carried out using hot or cold runner systems. In a cold runner system, the sprue feeds polymer to the runner, which in turn supplies polymer to each individual mould within a multi-cavity tool. The polymer is then fed through the gate into the individual mould cavities. This feed system cools and is ejected with the mouldings which then have to be removed from the cold runner as a separate operation. The removed plastic is then sent to waste or reground and fed back into the hopper along with virgin material at a controlled percentage. Hot runner injection moulding tools, though more expensive to design and make, overcome these issues. The runner is either insulated within the mould preventing the polymer solidifying, or it is heated to ensure the plastic is held at the most efficient temperature. These 'hot runner' systems reduce waste and increase cycle time. Hot runner mouldings are now commonplace in plastic packaging applications.

14.6.3 Decoration of injection moulded parts

Just like paperboard and plastic films, injection moulded parts can be decorated by vacuum deposition of metals such as aluminium. Other types of decoration are possible and are covered in Chapter 18. Mould surface treatments such as spark erosion is used to give special effects, and mouldings can also be laser etched or coloured in



14.34 Hot runner mould (courtesy of Kortec Inc.; www.kortec.com).

a variety of ways. Colours can also be added together, to give unique multicolour effects, by using masterbatches of dissimilar MFI.

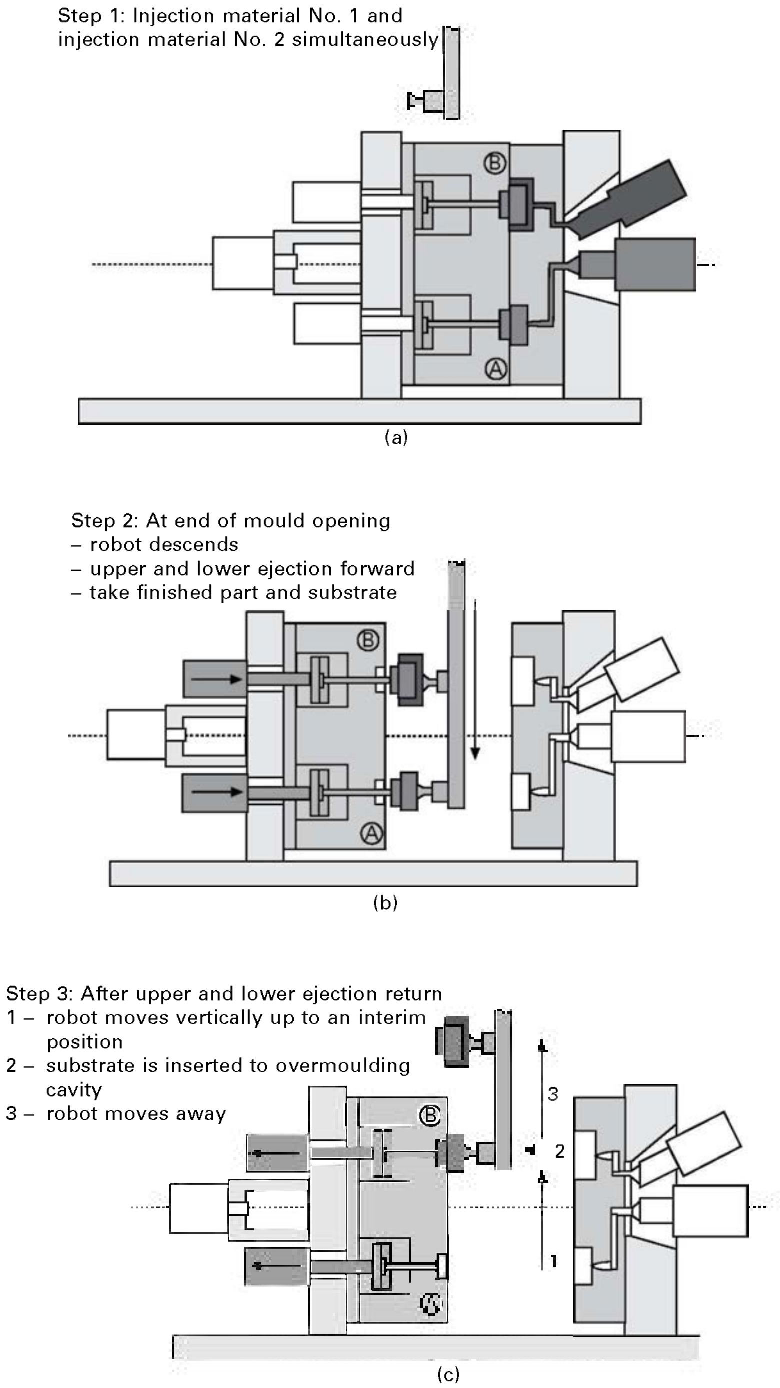
14.7 Multi-injection moulding

Multi-injection systems are used where more than one polymer or colour is required. This can be achieved in two ways:

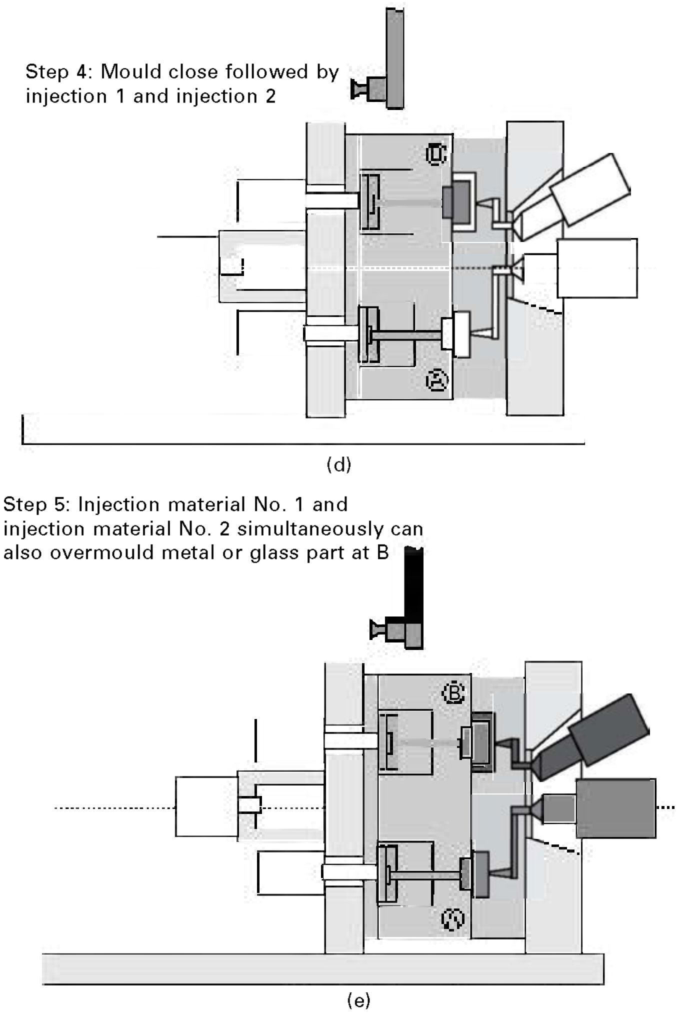
- Two-stage injection moulding and overmoulding
- Single stage coinjection.

14.7.1 Two-stage injection moulding and overmoulding

The two-stage injection moulding process can be used to produce a component with different coloured areas or with a core and an outer skin (Fig. 14.35). For example, the core could be foamed product of one polymer, the skin could be a completely different polymer. Overmoulding of another object is also possible, e.g. overmoulding of a glass bottle with a clear resilient plastic such as an ionomer or a thermoplastic elastomer (TPE). The first polymer is injected into the smaller mould, the item is removed from the mould and inserted into a second mould adjacent to the first. This second mould is closed and the second polymer injected around the first moulding. The first stage can be injected at the same time as the second stage, once the process has started, therefore reducing cycle time. Overmoulding of glass and metal can be carried out in the second mould.



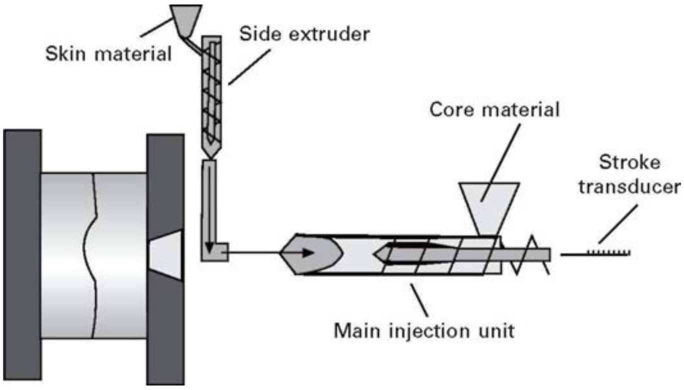
14.35 Two-stage overmoulding process: (a) step 1; (b) step 2; (c) step 3; (d) step 4, (e) step 5 (courtesy of Husky Injection Moulding Systems; www.husky.ca).



14.35 Continued

14.7.2 Single-stage coinjection

The single-stage coinjection process is shown in Fig. 14.36. The main polymer, e.g. PET when moulding a preform for injection stretch blow moulded bottles, is delivered from the first extruder. As the molten polymer travels along the hot runner system, a second extruder injects another polymer, for example PA. The more viscous PA travels through the core of the less viscous PET. The melting temperature of the materials should be similar. The main material (PET) is first injected into the neck finish of the mould. The core material is injected into the body portion of the preform. The base, like the neck finish of the preform, contains little or none of the core material to ensure maximum strength is achieved when the bottle is blown. The injection system is carefully sequenced to ensure the core material is delivered to the



14.36 Single-stage coinjection process (adapted from Giles, G. and Bain, D. (eds), *Technology of Plastics Packaging for the Consumer Market*, Wiley, 2001).

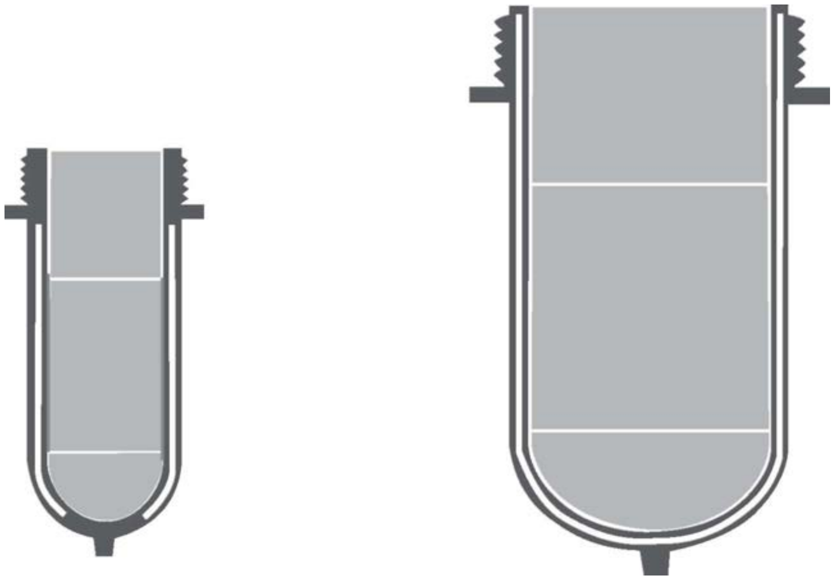
exact areas required, during the coinjection process, using a hot runner coinjection system.

One of the main uses for this technology is PET bottles and jars requiring an improved oxygen barrier and, in the case of carbonated beverages, a carbon dioxide barrier. The two types of barrier materials used are ethylene alcohol-based polymers and special polyamide and polyester polymers. The polyamide and polyester-based polymers actually act as oxygen scavengers, preferentially absorbing the oxygen as it passes through the PET, thus reducing the amount of oxidation of the contents of the container. Polyethylene naphthalate (PEN) is sometimes used as a minority percentage blend with PET, to improve the UV barrier and processability. It is, however, restricted in its use due to its high cost. To allow for easier recyclability, the different material layers in the coinjected preforms are not tied together. Once the neck is cut from the blown bottle and the bottle ground into small particles, the two polymers can be separated by water flotation and other methods. Where preforms are made combining PP and PET, as shown in Fig 14.37, the core barrier layer in the PP preform has to be incorporated all round the preform, including the neck and base areas. This is because PP has less barrier to oxygen than PET.

14.8 Comparing injection moulding and thermoforming

Table 14.2 compares injection moulding and thermoforming. Key issues to bear in mind in choosing between the two include the following:

- The amount of material used to make thermoformed items is always greater than for injection moulded items. This is because the injection moulded items only require the exact amount of material to fill the mould (thick and thin sections are predetermined at the design stage so as to reduce the amount of material). The thermoforming process relies on a sheet of material of even thickness.
- Thermoforming thins the walls as they stretch resulting in more material being required to compensate for the thinning. Once formed, the items have to be cut



14.37 Coinjected PP and PET preforms (courtesy of Kortec Inc.; www.kortec.com).

Table 14.2 Thermoforming versus injection moulding

Thermoforming	Injection moulding
Not suitable for all materials	Suitable for all materials
Expensive material	Less expensive material
Less expensive tooling	More expensive tooling
Less time to make tooling	More time to make tooling
Multi-barrier less difficult	Restriction on barriers
Less accurate dimension	Excellent accuracy
Undercuts restricted	Undercuts possible
Poor distribution of material	Excellent distribution of material
In-mould labelling difficult	In-mould labelling possible
Good for short runs	Less suitable for short runs
Surface effects limited	Many surface effects possible
Lip or rib on packs	No lip or rib on packs

from the multimould, creating waste. Hot runner injection moulding creates no waste.

- The tooling costs for injection moulding are in general more expensive than for thermoforming, due in part to the extra accuracy required and the pressures involved in the process. However, the costs as well as the time required to make the tooling for both processes is becoming very competitive.
- Multilayer sheet for the thermoforming process is straightforward to produce, but multilayer injection moulding is still being developed, therefore predetermined barrier requirements are less difficult to produce with thermoforming than with injection moulding.

- Thermoformed mouldings do not have the high level of dimensional accuracy of injection moulded items. The thermoforming process relies on pressure and/or vacuum to form the semi-molten sheet into a mould. Injection moulding forces molten polymer into a precisely formed tool, under high pressure, ensuring the moulding conforms to the design of the tool.
- Undercuts are restricted to very shallow ones, on thermoformed mouldings. This is governed by the ability to remove the moulding from the mould. Injection mould tooling can accommodate any undercut by designing special tooling.
- Accurate screw threads are not possible with the thermoforming process.
- The distribution of material when in sheet form is consistent, therefore the material distribution after thermoforming the article is far less controllable than with the injection moulding process. As a result, mechanical and barrier properties are much more variable in thermoformed articles compared to injection moulded items.
- The temperatures and pressures involved in the manufacture of thermoformed articles are much less than in the injection moulding process. This results in the adhesion between in-mould labels and the moulded item being far superior in injection moulding.
- Injection moulding is comparable in cost to thermoforming on long runs (millions of items), especially when thin wall injection processes are used for such items as tubs for yellow fats.
- Thermoforming leaves a lip on packs, where the moulding has been cut away from the remaining sheet. There is also a tendency for a rib to be formed just under the orifice of the thermoforming where undue pressure has been applied to the moulding while still soft. Neither of these phenomena occur with injection moulded items, though in a moulding where there are thin and thick sections, sink marks can occur due to the extra shrinkage of the thicker section.

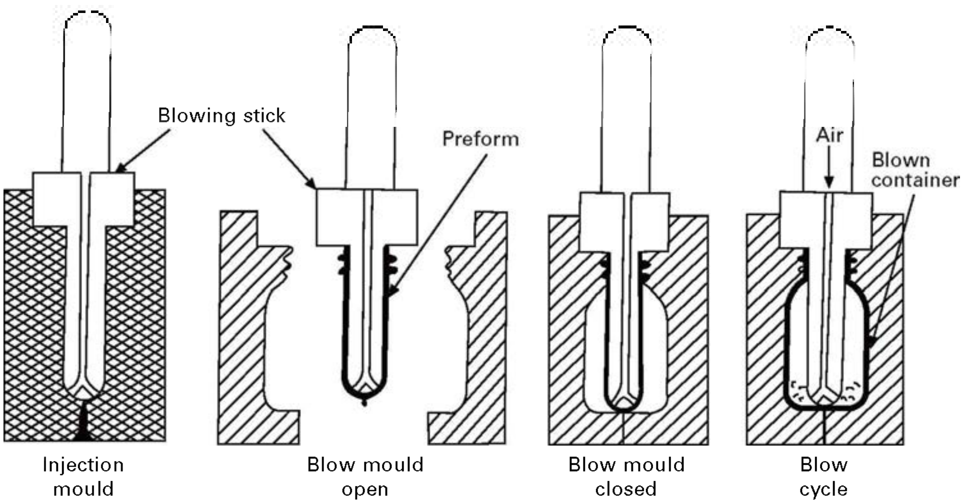
14.9 Blow moulding

Blow moulding can be achieved via an injection, extrusion or combination process. It is used where the orifice of the moulded item is smaller than the overall cross section of its body, for example bottles and jars.

14.9.1 Injection blow moulding

Injection blow moulding is a combination process. First, we have to injection mould a preform and then blow it into the shape required, thus two moulds are required: one for the preform and one for the final blown form. The following methods can be used for producing blown mouldings from an injection moulded perform.

The two-stage blow moulding process is used for standard and stretch blow moulded items (Fig. 14.38). The preform is injection moulded as a separate stage, in a separate machine. The preform is designed to have a profile and variable wall thickness to provide the correct mechanical and barrier properties in the final blown moulding. Once moulded, the preform is reheated (different zones of the preform are

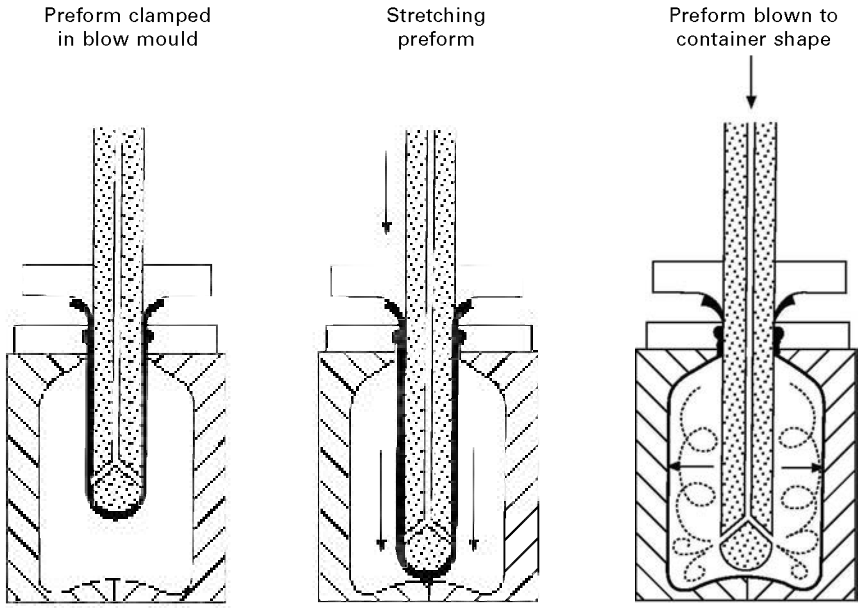


14.38 Injection blow moulding process.

heated to different temperatures to best suit the final blown form requirement) and placed in the blow mould. Air is introduced via the preform neck and the preform is blown into the shape of the mould. Venting is necessary so that all trapped air is removed from between the moulding and the mould. The mould has cooling ducts incorporated into its design. The coolant is usually water maintained at a constant temperature. To produce bottles suitable for carbonated beverages, the gas barrier and mechanical properties (tensile and burst strength) of the final bottle have to be greater than for a non-carbonated product not requiring a gas barrier.

Stretch blow moulding can be carried out on both injection and extrusion processes (Fig. 14.39). In injection (the most common use) stretch blow moulding, the preheated preform held on the stretch rod is placed in the blow mould. Both the rod and the preform are heated to a controlled constant temperature, usually just above the T_g of the polymer, the bottle finish area being kept cool so that it does not distort. Once in the blow mould, the stretch rod pushes the preform to the bottom of the blow mould, air is introduced through the rod which expands the preform to the shape of the blow mould. In this way the material is orientated in both directions; this improves clarity, mechanical and barrier properties. Very lightweight bottles with good moisture and carbon dioxide barrier and pressure resistance properties can be produced using this method. Improved oxygen barrier can be obtained by using barrier materials such as polyamides and polyvinyl alcohol, the former can be added as a monolayer, but usually the barrier (oxygen scavenger) is added as a separate layer in the centre of the preform.

Injection moulds for the bottle industry are multi-cavity (over 100 per tool) to ensure the cost is kept to a minimum (Fig. 14.40). The preform is so designed that once the bottle is blown, the neck finish and base are five times thicker than the wall of the final bottle. The incorporation of a barrier layer to the preform structure extends the shelf life of the packed product (e.g., beer) to an acceptable level. Barriers are also used in wine bottle manufacture but often added in the monolayer, rather



14.39 Stretch blow moulding process.

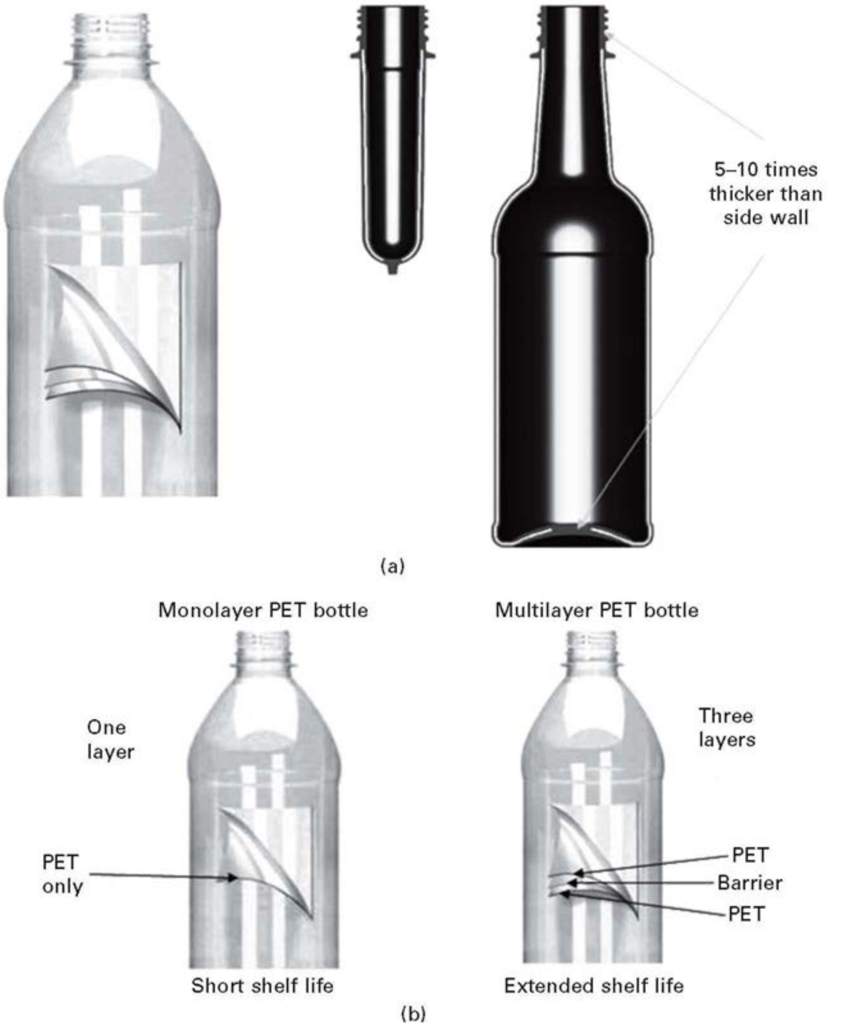
than coinjected as for beer. As well as providing an excellent oxygen barrier, it is claimed to offer improved clarity compared to coinjected bottles.

Single-stage injection blow moulding requires only one piece of moulding machinery, but still requires two sets of tooling (one for the preform injection mould, one for the blow mould). The preform is injection moulded, transferred from the injection mould to a reheating station and then transferred to the blow moulding station where the item is formed, cooled and ejected. The benefit of this process is that, for small quantities of items (e.g., cosmetics and toiletries) all mouldings can be carried out by the packer-filler, in one process.

14.9.2 Extrusion blow moulding

Extrusion blow moulding is a less expensive process than injection blow moulding and can provide a wide variety of barriers and features such as handles, but the dimensional accuracy is not as well controlled (Fig. 14.41). Some materials such as PET and standard PP homopolymer are difficult to impossible to extrusion blow mould on a commercial basis due to their low melt viscosities. However, polypropylene and polyester copolymers are available which can be extrusion blow moulded acceptably. The parison (hot hollow plastic tube) is extruded through an annular die. The thickness of the parison is controlled in the die by varying the wall thickness of the parison, whilst leaving the outside diameter the same. This is accomplished by having a conical inner sleeve, which can be moved up and down in the die, resulting in a controlled variation in wall thickness of the parison (Fig. 14.42).

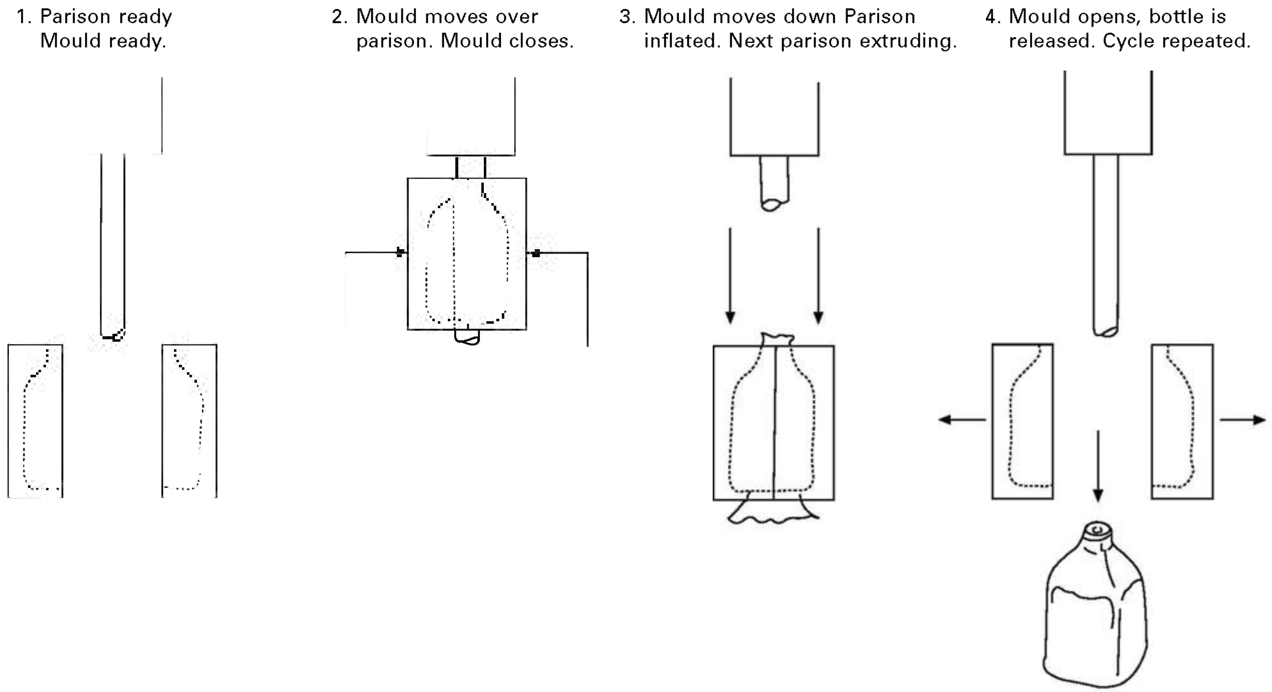
This control is important, especially when producing bottles of complex shape with widely different cross-sectional areas from base to neck, for example a cylindrical



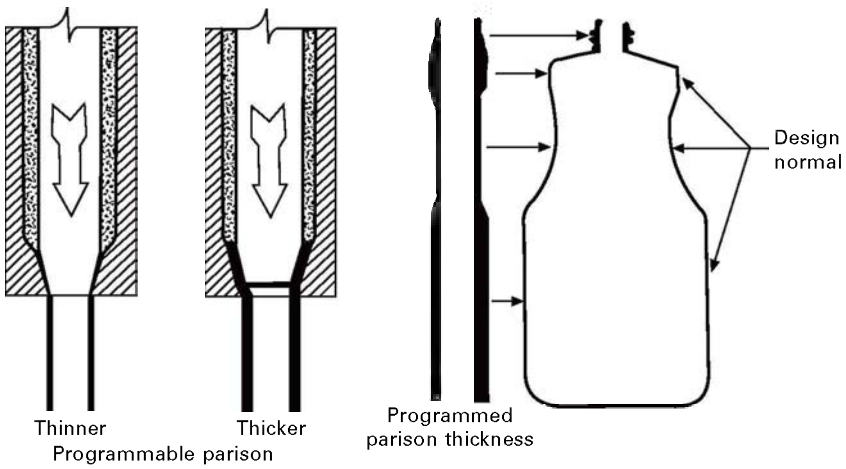
14.40 Multilayer injection moulded PET bottles (courtesy of Kortec Inc., www.kortec.com).

bottle with a heavily waisted section for ease of holding, or figurine-shaped bottles used for children's products. It is equally important for more regular shapes such as square or rectangular cross sections, where the plastic has to be stretched a long way from the centre at varying distances. The control of wall thickness of the parison is also important where, due to its weight, it flows downwards before it is taken into the blow mould (Fig. 14.43).

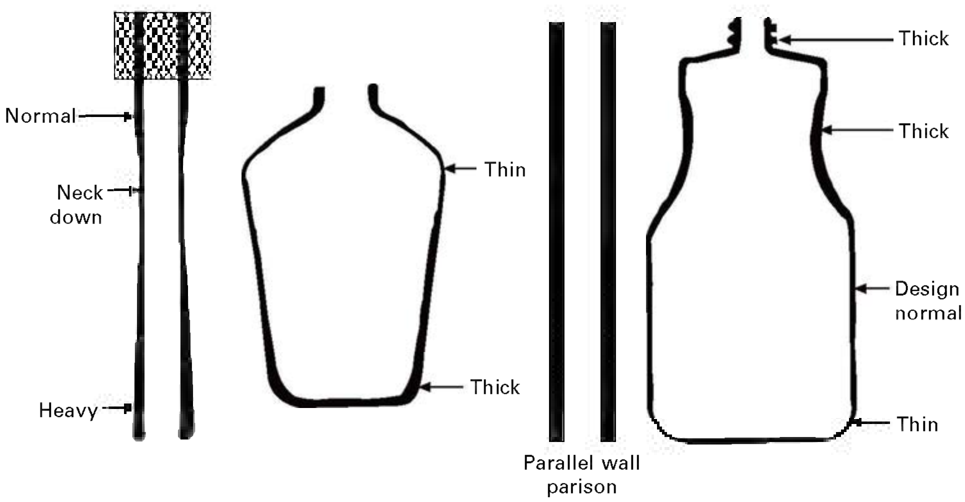
Parison thickness control is also important to ensure the correct weight of polymer is applied to the correct areas, based on the design of the final item, for example integral handles. To produce a handle, material needs to be 'stolen' from the parison. Sufficient material needs to be placed in the area of the parison where the handle is to be formed to allow this. It is also important to control the handle area so that



14.41 Extrusion blow moulding process.

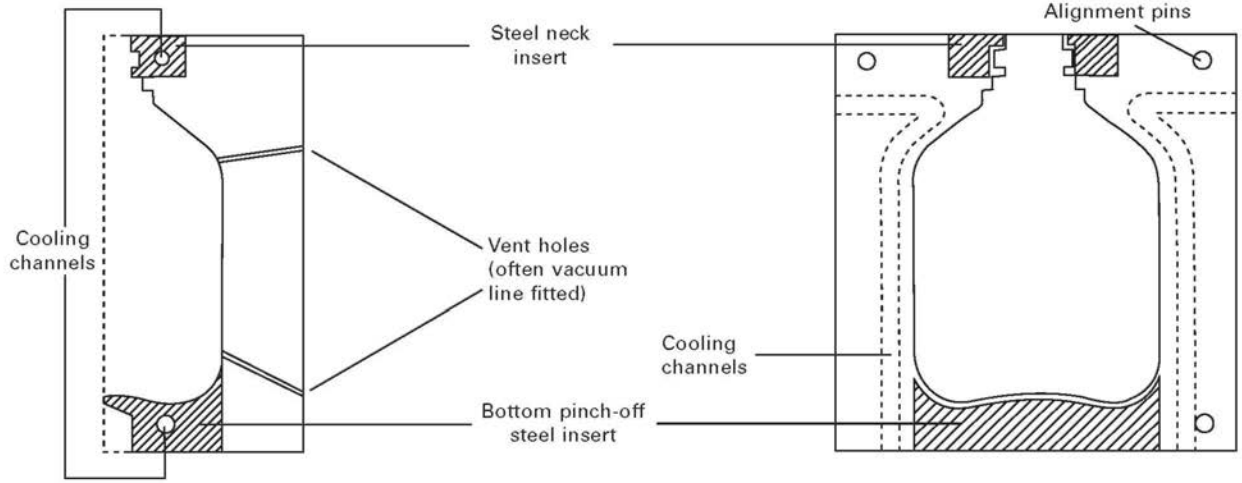


14.42 Control of parison thickness in the die.



14.43 Problems in controlling parison wall thickness: (left) parison 'neck down' due to weight and (right) inflation of parallel-walled parisons in containers with variable diameters.

a balanced moulding results. Sometimes the neck is designed to be away from the centre of the moulding. This too requires redistribution of the polymer to ensure good performance of the final moulding. The control of the parison wall thickness ensures a minimum amount of material is used to produce the final moulding without compromising its performance. The parison is extruded to a given length (the length of the blow mould) and the blow mould is closed around it. Once closed, air is introduced to the parison, blowing it to the desired shape. The moulding is ejected once cooled sufficiently so that it will not deform as it comes out of the mould (Fig. 14.44).

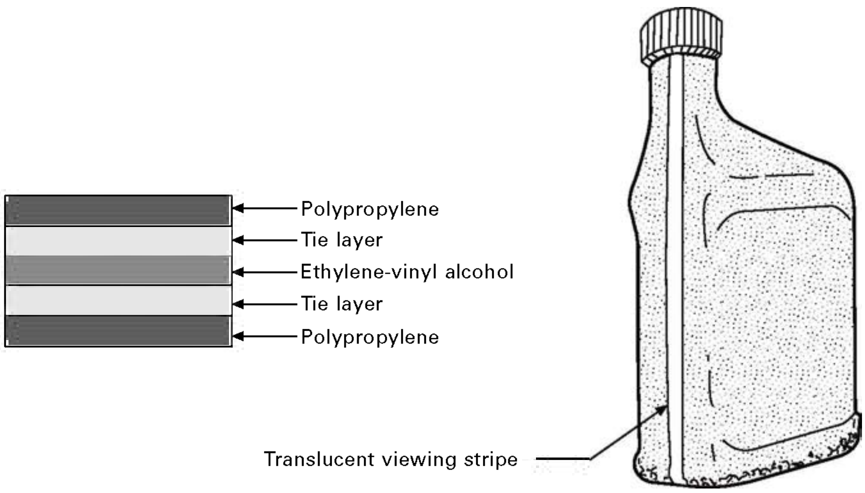


14.44 Cooling of moulding ready for ejection.

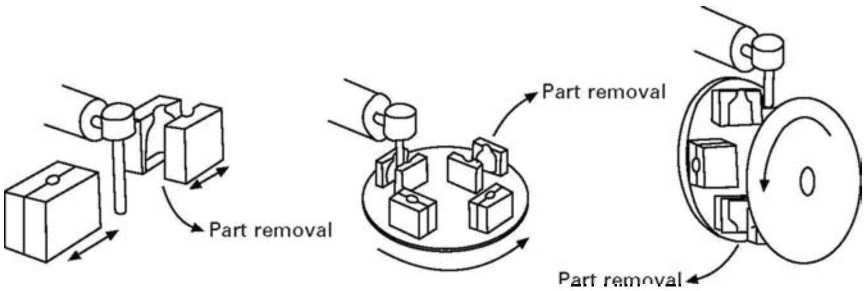
The moulding process requires the blow mould to seal the parison by pinching it together. This results in excess material being squeezed out when the mould comes together, and this excess has to be removed. This is carried out by transferring the moulding, contained in the mould to a stripping area, where the excess material is cut off with sharp knives. This action leaves a tell-tale scar on the base of the moulding. This is an easy way to differentiate between an item produced by injection blow moulding, which will show an injection point nipple at the bottom, from an extrusion blow moulding. The waste material is, where acceptable, reground and coextruded, as a sandwiched layer within the parison, thus reducing waste and keeping costs to a minimum.

Multilayer extrusion blow mouldings are now the norm. The combination of different polymers provides a vehicle to increase the performance characteristics of the final moulding, whilst at the same time keeping costs competitive (Fig. 14.45). Multilayer preforms can be so designed as to leave the outside layer free of colour at a predetermined point, allowing for a translucent stripe to be incorporated, so that the product level can be seen. This is very convenient where multi-dose bottles are used.

The normal machine design for most extrusion blow moulding manufacture uses alternating moulds (either single- or multi-head). However, for very high volume on one design, rotary blow moulding machines are commonly used (Fig. 14.46) . Here the air can be introduced via a needle through the side of the parison rather than the more common method of through the centre hole. As the needle is introduced and extracted before the moulding cools the needle hole self seals. This type of rotary system is often used for moulding HDPE milk bottles.



14.45 Multilayer extrusion blow mouldings: layers for a high oxygen-barrier bottle (left) and a bottle with a coextruded transparent viewing stripe to view fill level (right).



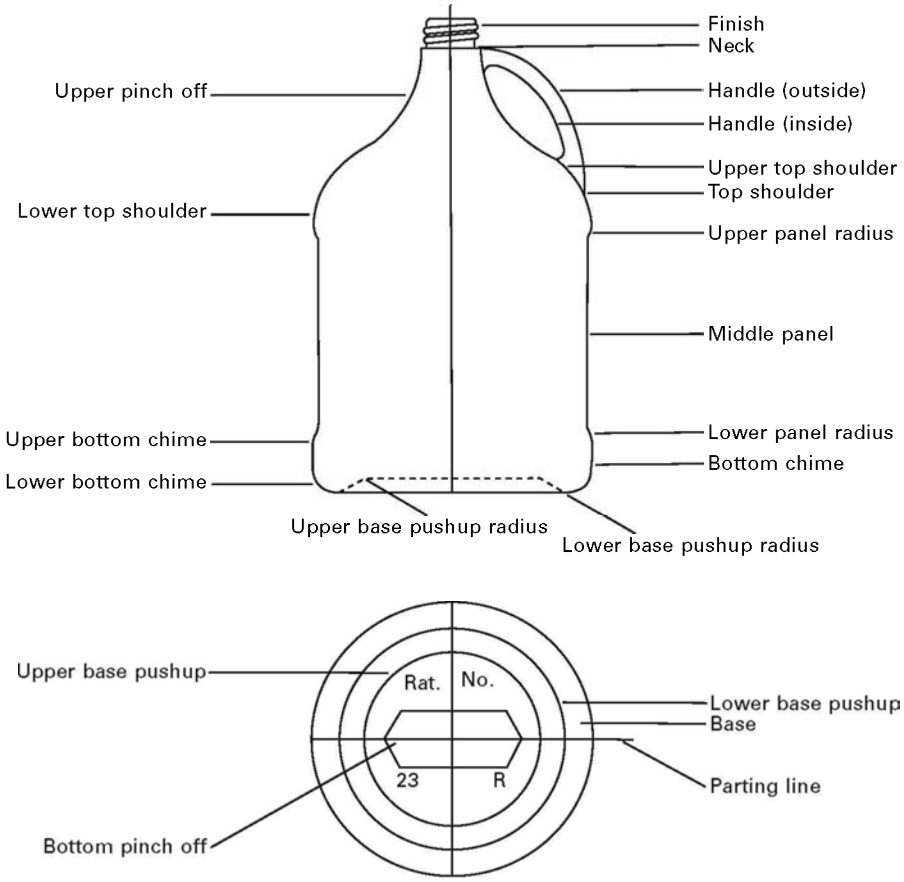
14.46 Alternating and rotary blow moulds.

14.9.3 Design specifications for blow moulded bottles

The standard terminology when describing bottles (and other blow mouldings) should be understood, especially when including in specifications (see Fig. 14.47 and Table 14.3).

Table 14.3 Typical specification for a carbonated soft drinks bottle

Resin intrinsic viscosity 0.78–0.82 g/cm^3
Volume
2,000 ml ± 20 ml (individual)
2,000 ml ± 10 ml (average)
Fill level drop
40 mm under 4 bar (function of the bottle shape)
Fill point variation (from bottle to bottle)
max 2.5 mm (function of the bottle shape)
Bottle creep (24 h filled with 4 vol. CO_2)
diameter increase max 3%
height increase max 3.5%
Deviation from perpendicularity
max 9 mm
Top load (empty and peak values)
>200 N (function of the design and weight)
Drop test
no leakage for bottle drop from 2 m height
Thickness
minimum 0.25 mm
in the heel 0.20 mm
CO_2 loss, shelf life
14 weeks with 15% loss CO_2
Stress cracking
15 min in 0.2% NaOH (weight) at 4 vol.
Burst pressure
>8 bar



14.47 Standard bottle terminology.

14.10 Environmental considerations in plastic packaging

As covered in Chapter 5, the environment is a serious consideration when choosing the type of packaging for a product. Plastic materials are often viewed by consumers and ill-informed bodies as environmentally irresponsible. However, the consumer only sees them lying in the street, and the complexities involved when determining if a particular packaging material or design is good or bad for the environment compared to the alternatives are not well understood. Whether polymers are used for single- or multilayer items, the properties required for the end use, cost and environmental issues are the main considerations which determine the type and thickness used. Plastic items are all recoverable in some way or another (re-use, recycle, energy recover, biocompost); their main advantage is in reducing materials used and preserving the products inside, at the minimum total cost. One of the difficulties of film with respect to re-use and recycle is the cost of collection and sorting, as not all polymers are compatible. Incineration for energy recovery is possible and this simplifies the sorting process, although it requires special incinerators to ensure there is no pollution from the gases produced during the burning process.

14.11 Sources of further information and advice

Baner, A.L. and Piringer, O. (2008) *Plastic Packaging Materials for Food*. Wiley, New York.

Baner, A.L. and Piringer, O. (2008) *Plastic Packaging: Interactions with Food and Pharmaceuticals*. Wiley, New York.

Giles, G. and Bain, D. (eds) (2000) *Materials and Development of Plastics Packaging for the Consumer Market*. Wiley, Oxford.

Giles, G. and Bain, D. (eds) (2001) *Technology of Plastics Packaging for the Consumer Market*. Wiley, Oxford.

Hernandez, R., Selke, S. and Culter, J. (2000) *Plastics Packaging*. Hanser, Munich.

Nicholson, J. (2011) *The Chemistry of Polymers*, 4th edn. RSC Publishing, Cambridge.

In addition to the above texts, the British Plastic Federation (www.bpf.co.uk) is a valuable source of information on all aspects of plastics, including material properties, industry applications and forming methods.

Other useful sources of information include:

- http://www.britishplastics.co.uk
- http://www.incpen.org
- http://www.packagingdigest.com
- http://www.packagingfedn.co.uk
- http://www.packagingtoday.com
- http://www.pafa.org.uk
- http://www.plasticsinpackaging.com

15
Packaging closures

A. EMBLEM, London College of Fashion, UK

Abstract: This chapter considers the important functions of closures, and reviews a range of different closure types. Closure material properties are not repeated here, and it is necessary to refer to the relevant chapters throughout the text. Specialist closure functions such as child resistance, tamper evidence and dispensing features are covered.

Key words: screw thread, push-fit, tamper evidence, child resistance, crown cork, lever lid, wad, liner, linerless closure, lug closure, peelable lid, ROPP, shrink band, flip top closure.

15.1 Introduction: the role of packaging closures

A closure can be defined broadly as any method for closing a pack so that the product is properly contained and protected. A more specific definition is a device that seals a product within a pack but which can be removed to allow the product to be accessed. There is a huge variety of closure types, including the following, defined by their method of application/achievement of a seal:

- push-fit closures
- screw-threaded closures
- heat-sealed closures (e.g. sachets, film lids and tablet blister packs)
- folded closures, often glued (e.g. cartons and cases, paper bags for flour, sugar)
- mechanical seaming (e.g. on metal cans)
- stitched or stapled closures (e.g. on paper sacks).

This chapter concentrates on closures which are usually added separately to a container, after filling, and used by the consumer to gain access to the product, i.e. mainly the first two categories above. The requirements of the remaining categories are addressed in the relevant chapters of the text, and are not discussed in detail here, e.g. the requirements of heat-sealed closures are discussed in more depth in the chapters on plastics properties and the packaging line.

Regardless of type, the closing method of a pack product containment is the interface between the product and the environment. It is also the critical interface between the product and the consumer and must meet a number of requirements:

- It must not contaminate the contents of the container or be degraded by them.
- It must be compatible with the container and its materials of construction.
- It must be able to withstand processing conditions such as sterilisation, and the

application of significant force (e.g. in tightening a screw cap or crimping a crown cork).
- It must be capable of withstanding vibration and temperature fluctuations during transport and storage as well as potentially rough handling by consumers in use.
- It must provide an adequate seal until the contents are ready for use. This may include protecting the product from air, light, moisture or foreign particles (e.g. dirt), providing an airtight seal or retaining a vacuum or internal pressure in the container.
- It must be convenient and safe to remove by consumers (who may have a wide range of abilities, e.g. the elderly with reduced manual strength and coordination).
- It may need to include child-resistant features which restrict access to potentially harmful products.
- It may need to include tamper-evident features to indicate whether a container has been interfered with in some way prior to purchase.
- It must often be resealable, capable of retaining an adequate seal once resealed and able to withstand repeated opening and closing.
- It must contribute to the overall aesthetic design of the pack.
- The type of closure and the method of application must be compatible with the overall volume and speed of production, particularly the requirements of the product filling line.
- It must meet the cost and operational requirements of the business, including acceptable design and material costs of closures, and acceptable set-up and operational costs of the packaging line.
- It must meet increasingly stringent environmental requirements, including minimising the amount of material used and facilitating recycling of the closure and container.

15.2 Types of packaging closure

This section starts by looking at the basic types of closure, such as push-fit, screw-threaded and lug closures, plus closures made by crimping. It then goes on to explore more specialised types of closure, offering features such as tamper evidence, child resistance and product dispensing or metering. Due to the wide variety of closures in each of these categories, it is not possible to cover all available options and discussion will concentrate on the principles of how an effective seal is achieved, rather than describing specific designs. A list of useful sources of further information is given at the end of the chapter.

15.3 Push-fit closures

Push-fit closures fall into two types:

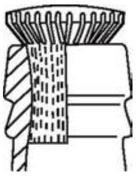
- Push-in closures: those in which the closure is pushed *in* the open neck of the container, e.g. a wine bottle cork, or the lever lid used on paint cans.

- Push-on closures: those in which the closure is pushed *on* or over the outside of the top of the container, e.g. the metal lid on a tin of biscuits or the plastic overcap sometimes supplied as a resealable feature on containers for dry products such as ground coffee.

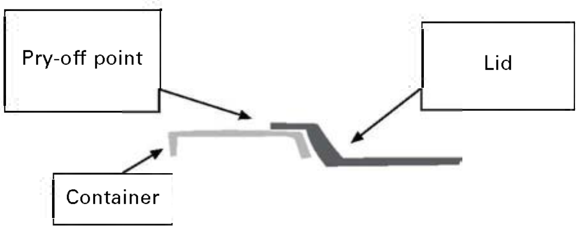
15.3.1 Push-in styles: corks, lever lids and plastic push-in closures

For push-in wine bottle closures, a seal is achieved as a result of the compression of the closure material against a rigid container surface which prevents excessive expansion. Cork and low density polyethylene are therefore ideal closure materials, and glass is the ideal container material to maintain a good seal (see Fig. 15.1). The quality of the seal can be enhanced by incorporating fins or serrations, which improve the flexibility and allow a tighter fit, with each fin creating a mini-seal as it presses against the container neck. Seal quality is enhanced by container design features such as a slightly rough surface and reverse tapering lower down the neck.

The push-in, pry-off lever lid design relies on a tight fit between the lid and container. To achieve an effective seal, both closure and container materials need to be sufficiently rigid to withstand the pressure imposed by pressing the lid into the neck of the container, container and closure tolerances need to be very closely controlled and the angles of the contact surfaces carefully calculated. Both the lid and neck typically include a rim and the neck is tapered to allow for some variation in dimensions as well as to increase the effectiveness of the seal (see Fig. 15.2). Metal clips are sometimes used for added security. This type of closure is easy to apply and provides a good seal but is vulnerable to damage from the levering action in opening and the pressure needed to reseal, often distorting the shape of the lid and aperture. Also, the seal area is easily contaminated, which compromises reseal quality. Lever lids (and containers) are traditionally made of metal but plastics are now widely used, e.g. for emulsion paints.



15.1 Push-in cork in glass bottle.



15.2 Push-in pry-off lever lid design.

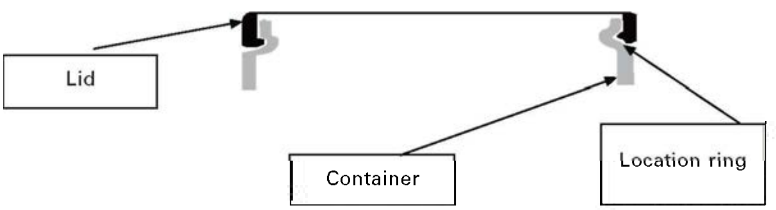
Push-in plastic closures are common for composite containers for dry products such as cocoa or custard powder. The lid is pushed into the top of the container and the compressibility of low density polyethylene makes it ideally suited to this application. However, the relative flexibility of the container (compared with metal) means that this is not an airtight seal and an aluminium foil diaphragm is often used to provide the required level of preservation, as well as tamper evidence. Once the diaphragm is removed, the seal provided by the push-in closure must be sufficient for the remaining life of the product.

15.3.2 Push-on styles: metal lids, plastic push-on closures and push-on twist-off closures

Push-on closures (also known as press-on closures) are easy to manufacture and apply, allowing high filling and sealing speeds. The simplest type is a metal rimmed lid (known as a slip lid) which fits over a metal container, e.g. as in a tin of biscuits. Since the fit cannot be so tight as to make opening difficult, the seal is relatively poor and, if the product is particularly prone to moisture gain, it will need additional wrapping inside the tin (e.g. a plastic film) to provide adequate preservation. To avoid the lid falling off in transit, and to provide a measure of tamper evidence, adhesive tape or labels can be used across the lid/container junction.

Push-on plastic closures must have good extensibility so that the closure can be stretched across the neck of the container to provide a good seal. Low density polyethylene is particularly suitable because of its good elongation properties. The container usually has a rounded lip to make it easy to remove and refit the closure, and there may be a locating ring to hold it in place (see Fig. 15.3). As with the push-in plastic closure already mentioned, additional features such as the use of an aluminium foil diaphragm may be required to provide appropriate product shelf life and tamper evidence.

There is widespread use of push-on plastic closures in the toiletries and household chemicals sectors, often incorporating flip-top or spray devices (see later). Design possibilities are numerous, with a wide variety of shapes and colours of both closures and containers. Locating features on the container are common, in some cases preventing the easy removal of the closure. Due to the relatively long usage period of such products, which means that the closure is subjected to repeated opening and closing, polypropylene is likely to be the material of choice, owing to its excellent resistance to flexing.



15.3 Push-on plastic closure design.

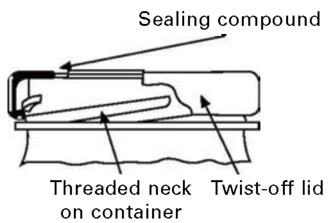
Push-on, twist-off closures (see Fig. 15.4), as commonly used for baby foods, are made from a tinplate shell, injected with a soft thermoplastic sealing compound. The product is hot-filled into the container (usually glass) which has an interrupted thread, and the closure applied. As the product cools, a partial vacuum is developed, pulling the metal closure down onto the finish of the container. The heat involved causes the soft flowed-in liner to conform to the shape of the threads. The final seal is effected by applying an appropriate torque in the capping machine, and the consumer opens the pack by unscrewing the closure. This type of closure is often given additional tamper-evident features such as a vacuum button (see Section 15.5) and/or an extended plastic skirt which has to be removed prior to unscrewing the metal part.

Categorising closure types can never be an exact science. Some screw-threaded closures, for example, are applied by push-on actions and these will be discussed in the next section.

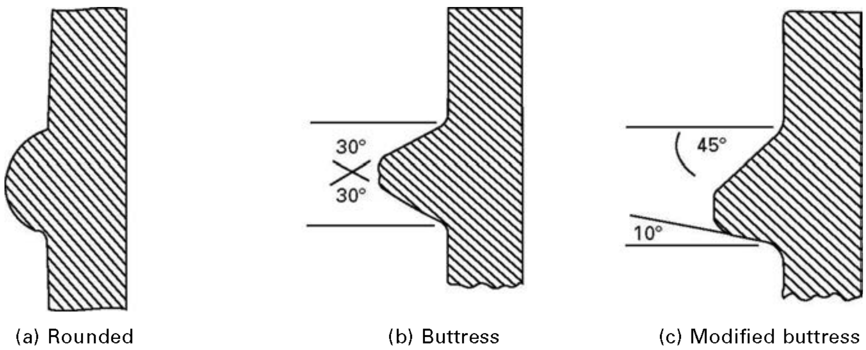
15.4 Screw-threaded closures

Screw-threaded closures have a thread following a helical (spiral) pattern on the inside, which must be matched up with the thread on the neck of the container. Ideally, the minimum thread rotation is 360°, giving one complete turn of thread engagement between container and closure. This is known as a 400 or R3 neck finish. Increasing the thread engagement results in a tighter seal, but requires more turns by the capping head on the packaging line. Standards exist for one and a half turns of thread engagement (410/R6 neck finish) and two complete turns (415/R4 neck finish).

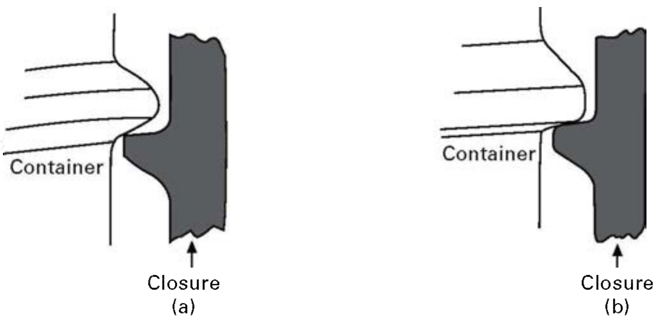
As well as the number of turns of thread, there are also options for the thread profile (see Fig. 15.5). The original profile, developed for glass containers, was rounded. However, using this same profile for plastic containers and closures did not allow the closure to be easily and accurately seated on the container, and severely limited the capping torque. Two alternatives were developed, the symmetrical buttress or L-style, in which the threads are angled at 30°, and the modified buttress or M-style in which the thread angles are 10° (lower) and 45° (upper). The latter has now become the most popular thread design for plastic containers and closures, as it provides both structural strength and ease of movement, allowing smooth closing and opening whilst maintaining reasonable seal quality when closed. It is also more resistant to the danger of over-tightening. Matching up the thread profile on container



15.4 Push-on twist-off closure.



15.5 Thread profiles: (a) rounded; (b) symmetrical buttress L-style; (c) modified buttress M-style.

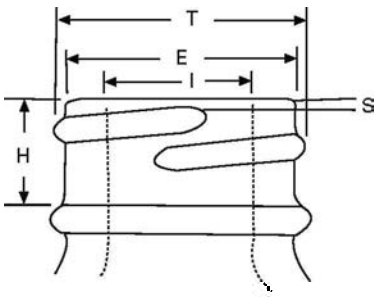


15.6 Importance of matching thread profiles: (a) symmetrical buttress container thread and modified buttress closure thread; (b) modified buttress thread profile used on container and closure.

and closure is essential for an effective seal. Figure 15.6(a) demonstrates that using a symmetrical L-style container thread and a modified buttress M-style closure thread provides minimum engagement compared to using the modified buttress style for both container and closure (see Fig. 15.6(b)).

Although many closure designs are specific to a particular product, closure manufacturers invariably offer a range of standard types. Dimensions are dictated by standard sizes of container necks and typically range from diameters of 12 mm to around 100 mm. These limits are restricted by the ease with which consumers can grasp and twist the closure to open it. There is a standard nomenclature for container dimensions, as shown in Fig. 15.7 and these must correspond on the closure thread, i.e. the container's 'T' dimension (diameter across the outside of the thread) must match up with the closure's 'T' dimension (diameter across the root of the thread). The same applies to the 'E' dimension, and the tolerances on the 'T' and 'E' dimensions on both container and closure must be such that:

- when the closure dimensions are at the minimum of the specification, and the container dimensions are at the maximum, the closure can still be easily applied to the container



I Diameter at smallest opening inside finish.
T Thread diameter measured across the threads.
E Thread root diameter.
H Top of finish to top of bead or to intersection with bottle shoulder on beadless designs.
S Distance from the top of the finish to the top of the start of the thread

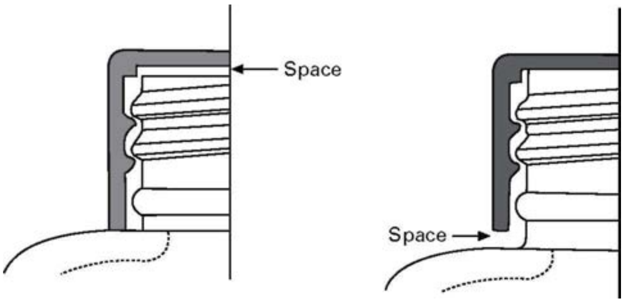
15.7 Standard nomenclature for container neck dimensions.

- when the closure dimensions are at the maximum of the specification, and the container dimensions at the minimum, the closure still sits correctly and delivers an effective seal.

This emphasises the importance of ensuring that tolerances are agreed prior to finalising specifications and that they are maintained throughout manufacture of the components. Should the need arise to investigate causes of leakage, a good starting point is to check the agreed component drawings to ensure that the specifications are correct, followed by measurement checks of both components, taking at least one sample from each cavity of container and closure, where multi-cavity tools have been used.

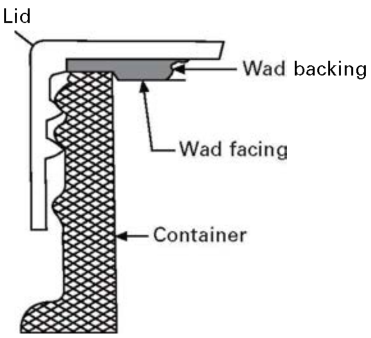
The 'H' dimensions of container and closure are also relevant. When the 'H' dimension of the container is at its maximum and that of the closure at its minimum, the capped container must still be aesthetically acceptable, i.e. the closure must not look too short for the neck of the container, with an unsightly gap between it and the neck ring or shoulder of the container (see Fig. 15.8(b)). More critically, when the 'H' dimension of the closure is at its maximum and that of the container at its minimum, there must still be engagement between the two components at the 'land' or sealing surface of the container. If not, there will be no containment, as there will be a clear path for product leakage (see Fig. 15.8(a)). This latter point raises the subject of how a seal is achieved in screw-threaded closures and how this differs in wadded and linerless closures.

Wadded closures are delivered to the packer-filler with a wad inserted by the closure manufacturer. The purpose of this wad is to act as a gasket between the top surface of the container and the inside top surface of the closure. When the threads of the two components engage and a tightening torque is applied, the wad is compressed, forming a seal (see Fig. 15.9). The effectiveness of the seal relies on correct choice of wad (see below) as well as correct closure placement and tightening. The wad must also be firmly secured in the closure, and this is achieved either by adhesive,



(a) (b)

15.8 Accuracy of 'H' dimensions: (a) container 'H' dimension is too short, resulting in product leakage; (b) container 'H' dimension is too long, resulting in an unsightly gap.



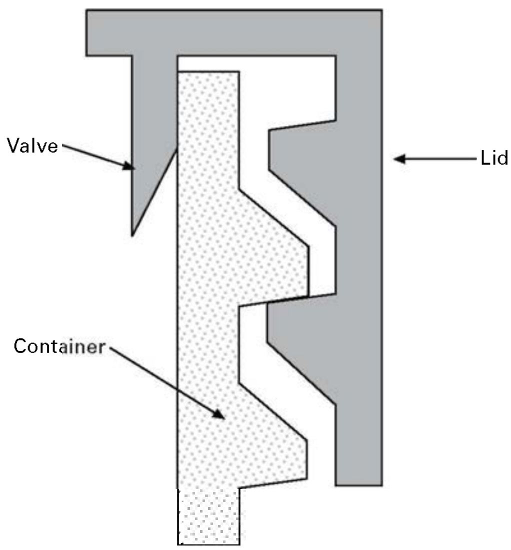
15.9 Wadded closure.

or by using an oversized wad which is forced into the space available, often held there by a retaining ring. If the wad falls out when the consumer opens the pack, and it is not reinserted into the closure, there will be little or no seal on reclosing the pack, resulting in potential contamination and/or leakage.

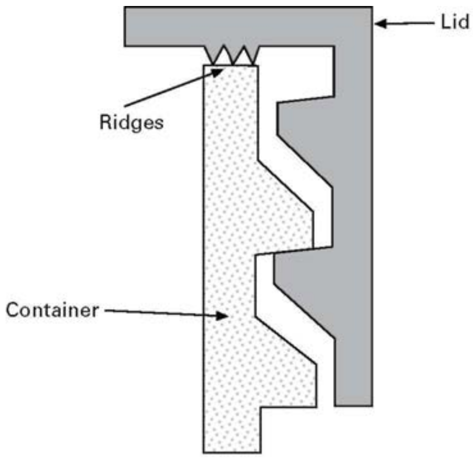
It is the wad which is in direct contact with the product, and therefore the wadding material must be compatible with the product and it must provide appropriate barrier properties to spoilage, e.g. due to gain/loss of moisture or gases. The wad must also be compressible, and exhibit some elasticity to recover from the compression exerted in use, especially for closures designed for multiple reopening and reclosing. Paperboard and foamed plastics both provide compression, with the latter providing better recovery. Paperboard alone will not provide barrier properties and thus it is usually laminated to a facing material such as aluminium foil, or films such as PET. Foamed plastics may suffice as barrier materials, but are also laminated to films (e.g. PET) for additional preservation.

Linerless closures, as the description suggests, have no wad and rely on direct contact between closure and container neck to effect a seal. They were developed as a lower cost alternative to wadded closures. Most commonly, they rely on a ring inside the closure fitting into the inside of the container neck (see Fig. 15.10). This type of seal is often referred to as a 'bore' seal and it relies for its effectiveness on very close control of the dimensions of both the closure and the container neck. In a wadded system, the internal bore diameter of the container is of minimal concern, as the seal is achieved on the top surface, but now that the bore has become the sealing area, this dimension becomes critical. This may dictate the container manufacturing method, making it necessary to use the two-stage injection blow moulding process rather than the simpler extrusion blow moulding process (see Chapter 14). There are many design variants available, with different ring depths (i.e. the extent to which the ring goes down into the container neck) and shape of ring, for ease of application via a simple push-fit, followed by tightening. Because of the pressure on the cap, the seal tends to weaken over time due to creep, and while high density polyethylene may be adequate for single or minimal use packs (e.g. mineral water, milk) polypropylene is a better option for multiple use over extended periods. Alternative designs involve creating the seal at the top of the closure, for example as shown in Fig. 15.11; as the cap is screwed on, the ridges bend under pressure to create the seal.

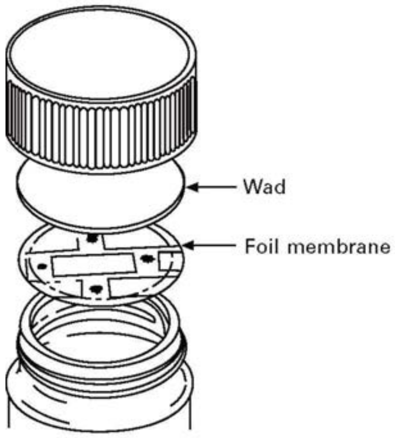
Screw-threaded closures can be designed to be linerless during consumer use, but are provided with a wad at the packer-filler stage, to ensure the pack withstands the rigours of distribution. A common example is the shallow closure used for milk bottles. This is supplied to the packaging line with a membrane inserted and it is applied to the filled bottle in a push-on manner and then the capped container is passed between induction heating coils. The membrane is usually a three-layer structure, composed of paper/aluminium foil/low density polyethylene. A metal layer is essential. The aluminium foil absorbs heat, which softens the polyethylene layer, which in turn bonds to the neck of the container, thus providing secure containment and tamper evidence. On removing the screw closure, the consumer peels off the membrane and recloses the pack using the plastic closure. As this is unlikely to be leakproof, it should be stored upright.



15.10 Linerless closure with bore seal.



15.11 Linerless closure with top seal.



15.12 Induction sealed combined wad and membrane seal.

Another variant is the use of a combined wad and membrane as shown in Fig. 15.12. The foil membrane is loosely bonded to the paperboard or foamed plastic wad, usually using a wax adhesive. During the induction heating process, the foil membrane adheres to the container via its polyethylene coating, as described above. The wad to membrane bond is weakened by the melting of the wax adhesive, so that when the consumer unscrews the closure, this bond breaks, leaving the membrane as a tamper-evident seal, and the wad retained in the closure for an effective reseal. Thus, unlike the membrane-only example above, the consumer can reseal the pack, and still maintain adequate sealing for the life of the product. Uses of this type of seal include jars of coffee and pots of vitamin tablets.

A further consideration is the material used to manufacture closures. Metal-threaded closures are made from malleable materials such as tinplate and aluminium, coated with various protective and decorative lacquers and inks, all of which must be suitable for the product and withstand all application and processing methods. Thermosetting plastics are used in some closures (see Chapter 13) due to their rigidity, resistance to creep and their ability to be moulded in high definition. However, the most commonly used plastics for closures are thermoplastics, especially the polyethylenes and polypropylene, which are easily formed and coloured. PP has significantly better resistance to creep than PE and is the better choice for multiple use closures.

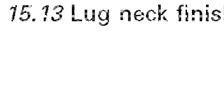
Finally, for all screw-threaded closures, the correct application torque is essential, so that the final fit is not too strong (which could lead to distortion, and/or the consumer being unable to safely open the pack) or too loose, which could result in leakage and contamination. This makes setting the right parameters on the machinery for applying screw caps to containers particularly important (see Chapter 20 on packaging operations). As well as application torque, which measures how tightly the closure is applied, other measures include removal torque, i.e. the amount of force necessary to loosen and unscrew the closure, and stripping torque, which measures the force required to override the closure so that the threads no longer hold it in place.

15.5 Lug closures

Twist-off metal lug closures, which require less than one turn to apply and remove (typically less than 90°), were developed by the White Brothers in the United States in the early 1950s. For this reason, they are often referred to as 'White' caps. Lug closures include lugs or protrusions on the inner edge, designed to engage with an interrupted thread on the container neck (see Fig. 15.13). They are secured by placing on the container, exerting a downward pressure and twisting so that the lugs slide under the thread to hold the cap in place. A seal is achieved between the closure and the container via a liner, which is usually a soft polymeric compound which is 'flowed in' during the closure manufacturing process, often applied only in the rim area.

Given the stress exerted on both closure and container, this type of closure is usually manufactured from heavy gauge steel and is restricted to rigid containers such as glass. They are available in 27 mm to 110 mm sizes with either smooth or fluted side walls, the latter allowing better grip for removal. Because less rotation is required, they can be applied at a higher speed than screw-thread closures. A further advantage is that the lug finish is easier to keep clean and free from sticky product than a helical thread, making this type of seal an excellent choice for jams and other preserves.

This type of closure is often fitted with a pop-up 'vacuum button' which indicates to the consumer, prior to opening, whether there is still vacuum inside the headspace. This provides both a tamper-evident and safety feature, warning a consumer if the product has been previously opened or if the container is defective. The vacuum button is typically created by embossing a ring in the top of the closure. The internal vacuum



15.13 Lug neck finish and closure.

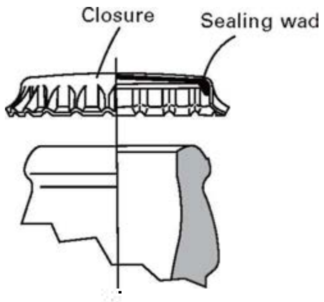
produced during the packing operation is sufficient to pull down the vacuum button (see Fig. 15.14). The button pops up once the cap is unscrewed and the pressure is released.

15.6 Crimped crown cork closures

These are widely used on bottles of beer and are typically made from heavy gauge metal, e.g. tin-free steel, with suitable coatings on both the inside and outside. They have a sealing wad inside the closure which may be cork (hence the name 'crown cork') or a compressible plastic, or, more commonly now, a flowed-in liner of soft plastic material around the inner circumference of the cap (Fig. 15.15). The closure is preformed and then placed over the neck of the container, often using magnets, and the outer circumference is compressed around the lip of the bottle and the edges tucked under a retaining ring on the lip to secure the closure in place, leaving a characteristically ribbed effect.

Crown corks are typically used for sealing glass bottles containing carbonated beverages, and are ideally suited to withstand the internal pressure of such products.

15.14 Tamper-evident pop-up button on metal lug closure.



15.15 Crimped crown cork closure.

The high seal integrity prevents air ingress or loss of carbonation, maintaining product quality. Unlike most closures, a bottle opener is required to remove the closure from the bottle (although a twist-off version is available) and once removed, the closure is deformed and cannot be reapplied. The simple design and method of application makes this type of closure relatively cheap and suitable for high-volume, high-speed production.

15.7 Peelable seal lids

In some cases sealing materials can be used as the lid, e.g. on yoghurt pots. Typical lidding materials include aluminium foil, paper, metallised PET or PP, often used in combination. A polymer layer on the inside is essential to effect the required heat seal. These lids are removed by peeling back, and the seal must be sufficiently strong to protect the product over its intended shelf life yet not so strong it cannot be opened by consumers. Many packs include a tab as part of the seal which the consumer can use to peel back the lid. Some designs include a sticky hot melt adhesive on the rim of the container protected by a polyethylene layer. Peeling back the lid fractures the polyethylene layer and exposes the adhesive. The lid can then be resealed. Materials and processes issues relating to this type of closure are discussed in Chapters 9 on aluminium foil, 13 on plastics properties and 20 on packaging machinery.

15.8 Tamper evidence

As already mentioned, a closure is the interface between the consumer and the product, and it must be convenient and safe to remove to gain access to the product. This means that it may be vulnerable to being opened before purchase, and, depending on the product, the brand owner may wish to provide some means of identifying whether or not such 'unauthorised' opening has taken place. Note that a 'tamper proof' or 'pilfer proof' pack is an unrealistic expectation and this section is concerned with the subject of tamper evidence, this being defined as 'having an indicator or barrier to entry which, if breached or missing, can reasonably be expected to provide visible evidence to consumers that tampering has occurred' (US FDA, www.fda.gov).

The key point in this definition is that it is important that the consumer can see if a container may have been tampered with before or at the point of purchase, so tamper-evident features must be obvious, rather than subtle. Where necessary, clear instructions should be given to the consumer (as shown, for example, in Fig. 15.14). It should also be noted that whilst most attention is paid to the pack closure, i.e. the main means of gaining access to the product, a determined tamperer may take a less conventional approach and mount an attack on another seal area of the pack. Thus, when assessing the tamper evidence of their products, brand owners need to consider the whole pack and not just its closure.

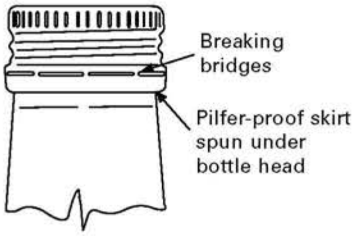
Tamper-evident closures abound in the fast-moving consumer goods (FMCG) sector. Some examples are:

- roll-on pilfer-proof (ROPP) metal closures and screw-threaded plastic closures, both of which result in a ring breaking away once the closure is unscrewed
- plastic closures with a tear-off section which has to be removed before opening the pack
- metal closures with pop-up buttons (already discussed)
- shrink seals or bands round the container/closure interface
- adhesive labels and tapes.

15.8.1 Roll-on pilfer-proof (ROPP) metal closures

Although inaccurately named, this is a firmly-established type of tamper-evident closure, made of soft-temper aluminium with a partially perforated ring (or skirt) at its lower edge (see Fig. 15.16). It is delivered to the packer-filler as a printed shell, without threads, and with a wad in place. It is placed on the filled container and the threads are rolled into the outside surface of the metal shell, conforming to the threads on the container. See Chapter 20 for details of its application on the packaging line. The pressure of the thread-forming rollers limits this type of closure to use with highly rigid containers such as glass bottles, and it is widely used for wines and spirits. When the closure is unscrewed, the perforated ring should fall away, leaving clear evidence of opening. The closure has the inherent design weakness that, since the metal is soft, the thread may be lost if it is over-tightened by the consumer when reclosing.

One variant of the ROPP design has the aluminium body of a roll-on closure, with a plastic moulded insert which is pressed in to give a tight fit between the two components. The insert (usually low density polyethylene) has internal threads moulded



15.16 ROPP closure.

into the side walls and is fitted with a wad. It provides two additional features to the standard ROPP closure:

- As the thread is internal, and provided by the insert, there are no unsightly threads on the outside, making it more aesthetically pleasing.
- As the internal thread of the closure is made from moulded plastic, it is particularly suitable for use with products which have high sugar content, such as liqueurs, where the traditional ROPP aluminium closure tends to become sticky over time, and difficult to remove.

15.8.2 Plastic tamper-evident closures

Plastic tamper-evident closures with a perforated ring or skirt added at the bottom of the cap are applied as conventional screw-threaded closures. Extra pressure is required to push the perforated ring at the bottom over a ridge or bead around the neck so that it snaps into a specially designed groove which holds it in place. The ring is held in place either by the thickness of the groove which keeps the ring stationary as the cap itself is unscrewed, or by teeth which engage with ratchets moulded as part of the groove. These prevent the capture ring moving when the cap is unscrewed. Opening the container breaks the perforations and allows the cap to be removed, leaving the ring in place.

Push-on closures can also be designed to include tamper-evident features, by using a deeper than usual skirt, the bottom of which snaps over a bead on the container neck. Above the bead, the closure is perforated so that the lower part can be torn off using a tab, thus allowing it to be removed completely. One disadvantage with this design is that, once removed, it may not be obvious to a consumer that a container had been interfered with, since the closure itself will still be in place. Sometimes the perforations are not carried all the way around the skirt, leaving a small connecting piece between the cap and the retained ring. This provides a 'captive' cap that cannot be easily misplaced.

15.8.3 Shrink seals or bands

As well as incorporating tamper-evident features in the design of the closure itself, secondary tamper-evident features can also be included, such as printed shrink sleeves. These are cylindrical sleeves of plastic film, placed loosely over a filled and sealed pack and then shrunk in place using heat (see Chapter 20 for packaging line application). Printed shrink sleeves are often used as pack labelling (e.g. soft drinks) and by extending the sleeve over the top of the closure they can also provide tamper evidence. In such cases, the sleeve should be perforated vertically to allow the consumer to gain access to the closure, and then horizontally so that the top part can be torn off without removing the entire label (and thus losing the branding). Alternatively, short shrink bands can be applied just to the closure area, again preferably perforated so that they can be easily removed by the consumer. As it is important that the consumer realises that there should be a shrink band in place, they should be printed so that they stand out as part of the product image.

15.8.4 Adhesive labels and tapes

Label seals can be self-adhesive substrates or ungummed substrates applied using adhesive applicators. They can be applied across the junction of a bottle/jar and its closure, or across the flaps of cartons. The label substrate must tear easily when the pack is opened, and must remain in place, so that it is clear that the label has been torn and the container tampered with. It must not be removable or repositionable. Some labels are constructed so that they disintegrate and others have a series of cuts that extend partially across the label to make it tear more easily and make it difficult to realign. Label seals should always be printed for maximum effectiveness.

There are various tapes used as tamper-evident devices, from simple printed self-adhesive tapes applied to corrugated cases to highly sophisticated double-layer materials which open to reveal warning statements such as 'void' or 'tampered with'. The latter have uses in the pharmaceutical sector, where the need to maintain pack integrity from packer-filler to consumer is crucial.

In summary, the extent to which packs are given tamper-evident features, and the types of features used, is determined by evaluating the risk of tampering and its possible consequences. Ultimately, brand owners are responsible for placing safe products on the market and it is up to individual companies to assess the risk to their products and take appropriate action.

15.9 Child-resistance

Packaging which is difficult for young children to open has been around since the early 1970s and there are international standards which such packs must meet. It is important to understand that these standards apply to packs, and not just to closures, and that alongside being difficult for children to open, the packs must not be difficult for adults to use. The standards also define 'young' children as those less than 52 months. As well as some pharmaceutical products, child-resistant packs are widely used for household product such as bleach and should be considered for any product which could be harmful to young children. Of course, this does not take away the responsibility of parents and others to keep harmful products out of the sight and reach of young children.

There are two relevant standards: BS EN ISO 28317 which applies to reclosable packs and BS EN 14375:2003 which applies to non-reclosable packs. Compliance with the standards is demonstrated by the results of two tests, a child test and an adult test. In the child test a panel of 30–200 children aged 42–51 months is given five minutes to open the pack, followed by a non-verbal demonstration of how it is opened and then another five minutes. Eighty per cent must fail to open it after demonstration. In the adult test, the panel is made up of 100 adults aged 50–70; 90% must be able to open, and (if relevant) reclose the pack in one minute. For non-reclosable packs, e.g. blister packs, 90% of the adults must be able to remove one tablet within one minute.

There are many designs of reclosable child-resistant packs, mostly applying the principle of having to carry out two different actions at the same time, which is generally not intuitive for young children, e.g. the need to both press down and turn a closure, or to squeeze and turn. In some of these designs a significant force is required to carry out these actions, adding a further barrier to a child gaining access to the container. The combination of coordination and force can be a problem for some groups of adults with reduced motor skills (e.g. the elderly). The requirement for cognitive skill (e.g. to understand and follow instructions for a set of coordinated actions) is preferable as a child-resistant feature to the requirement for significant manual strength which may be beyond some adults.

Single-use pharmaceutical products, whether tablets or edible capsules containing a liquid, are often contained in blister packs sealed with foil or a foil laminate. Access is gained by pushing the tablet or capsule through the foil. A key requirement is that both blister and foil must be opaque so that it is not possible to see the product inside and they must be durable enough not to tear easily.

15.10 Dispensing and metering closures

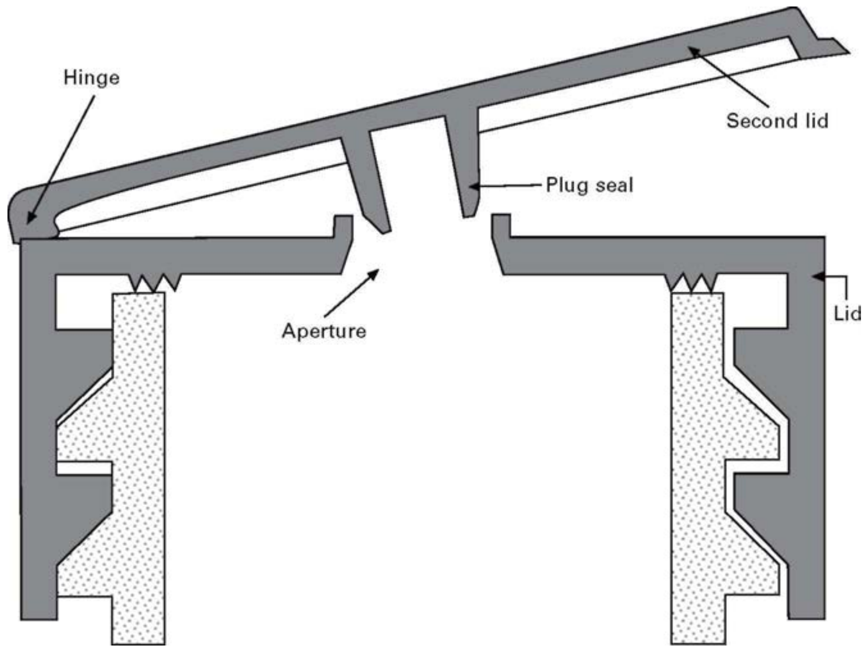
Designing a closure to aid the dispensing and/or metering of the product adds significantly to enhancing the convenience function of packaging, and the use of such features can make a difference to the selling function. The possibilities are many, from the simple use of the closure as a measuring device, e.g. laundry liquids, to the more complex systems used on pharmaceutical products such as asthma relievers.

Bearing in mind that most containers are filled through the open neck, one of the key requirements for packaging line efficiency and high speed is that the neck diameter is as large as possible. However, when it comes to consumer use of the product, this is a disadvantage as it could lead to too much of the product being poured out in one go. One easy way of dealing with this is to use some device to reduce the size of the neck orifice, after filling. This can be via a separate plug inserted in the neck, or a closure which includes a dispensing feature, such as a flip-top.

15.10.1 Flip-top closures

Flip-top closures have become particularly popular for such applications as controlled dispensing of a container's contents. Because of its particular requirements, this type of closure is typically made of polypropylene which can create a flexible hinge that does not break with repeated use. Flip-top closures can be either screw-threaded or push-on and are usually injection moulded as a single piece. The top of the inner part has an aperture of an appropriate size for the product, over which a hinged lid fits (see Fig. 15.17). A plug in the hinged lid section seals the aperture when the lid is in the closed position. The aperture may contain a one-way valve which holds the contents in even when the lid is open and the container inverted, e.g. in containers of shower gel designed to be suspended upside down. When closed, the lid is kept in place in the same way as standard push-on lids. It is usually designed to be opened by flicking it upwards, with one hand.

There are many variants of this basic design. The aperture, for example, may contain a nozzle, which may be fixed, hinged or may be extended out from the



15.17 Flip top closure.

aperture to allow more accurate dispensing of product. One variant used for bottled water and sports drinks has a screw cap, an extendable nozzle and a protective overcap, incorporating tamper evidence as well as ease of use when 'on the run'.

As for other closures, a key requirement here is the careful specification of dimensions for all closure parts (as well as the container, of course) and tight control of the manufacturing processes to ensure that specified tolerances are met. Injection moulding is invariably used for closures and, depending on choice of material and level of accuracy demanded, injection blow moulding may be essential for container manufacturing (see Chapter 14).

15.10.2 Dispensing pumps

Trigger-operated spray pumps are ideal for dispensing liquids such as household cleaning products. They can be fitted with either screw-threaded or press-on closures, the latter being easier to apply on the packaging line. Because the action of squeezing the trigger can loosen a screw closure, bottle necks for spray pumps frequently incorporate an 'anti-back off' feature that locks the closure once it is fully engaged. This prevents accidental loosening during use but still allows the pump to be removed either to allow refilling or to separate for recycling. Lined or linerless valve seals are used to create an effective seal. Again, closure and bottle neck dimensions must be closely controlled.

Dispensing pumps are used for a range of products, including high viscosity liquids such as hand wash and emulsions such as hand lotion. Here, the usage action is to press down the dispensing nozzle, which can usually be done with one hand, releasing an appropriate amount of product. They are sealed and applied in the same way as trigger spray pumps. To prevent accidental spillage before their intended use, the pump is often locked in the down position and needs to be rotated so that it can be released.

15.11 Testing closure performance

Regardless of closure type, testing its performance is essential, throughout design and development, manufacture, application and consumer use, as well as during storage and distribution. As already mentioned, close attention to dimensional tolerances is paramount and this must start at the design stage and include the container to be used.

During development, samples must be checked for conformance to specification, including all key dimensions, presence of the correct liner (if applicable) and liner retention. Fit to container for correct seal efficiency should be checked at this stage, before full-scale component manufacture is sanctioned. Options available include using a coloured dye around the sealing surface of the container, to check that closure and container are properly aligned, with maximum contact at the seal area. Other types of tests are designed to check if the closure has adequately fulfilled its functions of containing and preserving the product, e.g. weight or volume tests after storage for a predetermined period (possibly using accelerated conditions of temperature and humidity) or microbiological testing.

Usage tests should be carried out, to confirm that the closure fulfils its intended features of openability, dispensing the right amount of product, and ease of reclosing. For maximum benefit, such testing should be done under actual conditions of use, so testing a closure for a shower gel in the office environment will provide limited information. Carrying out consumer usage trials is a better approach, although it adds to the cost and time of development.

During closure manufacture, samples must be checked for conformance to specification as above, as well as for visual aspects such as surface defects, e.g. flash at the mould part line, prominent injection point, or unfilled moulds. Colour should also be checked against the agreed standard.

On the packaging line, seal efficiency can be checked by a variety of methods, both on-line and off-line. Typical on-line tests include simply inverting each filled pack, or subjecting each to a squeeze test, by narrowing the gap through which each passes. Channelling packs through a height detector may also be used to check and reject any which are above the standard, possibly due to the closure not being seated correctly and fully screwed/pushed into position. Statistical off-line tests (i.e. taking an agreed number of samples off the filling line at agreed time intervals) include measuring take-off torque, as well as carrying out visual checks.

The degree of testing to be undertaken will vary from product to product. A new design for a pharmaceutical dispenser closure, or one for a hazardous chemical will require a more rigorous approach than, say, a push-on lid for a tub of safety pins.

Regardless of this, agreed test protocols are essential and testing must be carried out by trained personnel using properly calibrated and maintained equipment.

15.12 Bibliography and sources of further information

Several general texts on packaging materials and technology will contain sections on closures. The following texts are specific to closures:

Emblem, A. and Emblem, H. (2000) *Packaging Prototypes 2: Closures*. RotoVision, Crans-près-Céligny.

Theobald, N. and Winder, B. (2006) *Packaging Closures and Sealing Systems*, Sheffield Academic Press, Sheffield.

The following internet reference may also be useful:

http://www.packaging-gateway.com/features/featuresafety-first-child-resistant-packaging/

16
Adhesives for packaging

A. EMBLEM, London College of Fashion, UK and
M. HARDWIDGE, MHA Marketing Communications, UK

Abstract: Adhesives are ubiquitous in packaging, whether applied to a packaging component by the converter or the packer-filler. This chapter explores the theories of adhesion, i.e. what makes materials stick together, and then reviews the properties of the main classes of adhesives used in packaging. A brief overview of adhesives application methods is given.

Key words: starch, dextrin, polyurethane, acrylic, casein, latex, polyvinyl acetate, hot melt, cold seal, borax, peel strength, coating weight, tack, green bond, wetting out, viscosity, fibre tear.

16.1 Introduction

Adhesives are critical to the structure of most packaging, whether applied during the conversion process or on the packaging line. Selection of the appropriate adhesive is vital to make sure that the pack will meet its performance criteria throughout the production, distribution and retail chain, and consumer use. From a production perspective, adhesive choice can significantly affect line efficiency and production performance. Adhesives are central to pack performance and it is important to understand how the various types work, the broad principles underlying their operation, how to get the best performance in use and how to troubleshoot adhesion problems.

Adhesives come in many forms and types and choice will be determined by the substrates being bonded (the 'adherends'), the machinery in use in the process and other factors, for example the potential requirement for food safe materials. Most adhesives are applied via specially designed machinery, adding another layer of complexity to the selection process and requiring adhesives with specific properties to match the operating parameters of the equipment. In some cases, adhesives are designed specifically for a particular machine type or model. Some of the terminology used throughout this chapter may not be familiar. Refer to Section 16.9 for explanations of commonly used terms in the adhesives industry.

16.2 Adhesives in packaging

An adhesive will either be supplied directly by an adhesives manufacturer for the packaging converter or packer/filler to apply on the production/packaging line, for example hot melt adhesives for carton closing or casein adhesive for bottle labelling; or it may be pre-applied to a substrate, for example as a self-adhesive label or a heat-seal coating for blister packing or lidding. Probably the majority of adhesives are supplied 'unseen' to the packer/filler and then to the consumer, as part of the structure of the packaging, for example laminating adhesives in flexible packaging, starches used in corrugated board making and cardboard tube winding, or PVA adhesives used in the side seams of folding cartons.

Examples of adhesive use by the packaging converter include:

- case and carton manufacture
- paper bag and sack making
- tube winding
- flexible packaging lamination
- remoistenable gummed tapes and labels.

Examples of adhesive use by the packer/filler include:

- sealing of cases and cartons
- labelling of cans, bottles and other containers
- closing, and in some cases forming of paper bags, e.g. for sugar and flour.

16.3 Theories of adhesion

In practical terms, an adhesive exists to bridge two surfaces, creating an intimate connection between them. In order to do this the adhesive has to completely fill the gap between them, and has to be sufficiently strong in itself that its structure will not break down under the adhesive joint's normal working conditions. That is, it must be not only adhesively strong but must also be cohesively strong. In production line operations, adhesives are often blamed for pack failures when the failure is in the adherends themselves, for example a weak laminate structure. In order for an adhesive bond to be made, a number of key criteria have to be satisfied. Firstly, the adhesive has to be able to make intimate contact with both surfaces to be bonded. That is, it has to have a sufficient affinity for both adherends so that it is able to 'wet out' the surfaces, filling all irregularities in the materials and flowing over the entire sealing surface without leaving voids. The adherend surfaces must be clean and free from contaminants and the amount of adhesive applied must be just sufficient to coat the surfaces.

As implied above, adhesives are generally applied as liquids which then become solid as they lose their carrier or solvent, or as they cool. The major exception to this is the pressure sensitive adhesive most commonly encountered as case sealing tape or as a pressure sensitive label. This behaves differently in that the adhesive layer must remain 'liquid' until the tape or label is applied to the required surface. Pressure sensitive (or self-adhesive) labels are covered in Chapter 17. The different theories of adhesion will now be discussed in terms of the mechanism of bonding. It is important to note that more than one mechanism may be present within any one bond.

16.3.1 Mechanical adhesion

In mechanical bonding the adhesive flows into the surfaces of the adherends and anchors them together once it has solidified, using an interlocking effect. The adhesive sits at the interface between the two adherends. The bonding of paper and board (e.g. carton side seams) is an obvious example of mechanical adhesion. The greater the penetration of adhesive into the two surfaces, the better the bond, thus the properties of surface roughness and absorbency are important. Surface lacquers can seriously impair adhesive penetration, and this is why any adhesive areas must be left clear of lacquer during printing of paper and board. Similarly, heavy clay coatings which are likely to be both smooth and non-absorbent will reduce adhesive penetration; one way of addressing this is for the carton converter to incorporate small cuts in the clay coating during the cutting and creasing stage of manufacture. As already mentioned, there is rarely only one mechanism of adhesion in place, and in the example above it is likely that there is also a component of the bond that is due to a specific or chemical attraction between the adhesive and the adherend. As long as the *cohesive* (internal) strength of the adhesive film is sufficiently high, failure of a mechanical bond is almost always due to insufficient strength of the substrates.

16.3.2 Specific or chemical adhesion

The bonding of rough and absorbent surfaces has been explained by the mechanical adhesion theory but this does not explain the bonding of smooth surfaces such as metal or glass, or relatively impenetrable materials such as polymer films. Specific adhesion theory proposes that there is an attraction between surfaces in intimate contact via short range molecular attractions called van der Waals forces. These are very weak electrostatic attractions which exist between all atoms and molecules, at all times, due to their positive and negative charges. The larger the atomic or molecular mass of a substance, the stronger the van der Waals forces. There must be sufficient adhesive at the interface between the adherends to make maximum use of the available bonding area, and the substrate surfaces must be receptive and not repel the adhesive. This is especially important for polyolefins, which have low surface energy. Refer to Chapter 12 for further explanation, including surface treatment options.

Any smooth surfaces brought into contact will weakly attract each other. A common example is the bonding between a microscope slide and a cover slip; the addition of a very tiny amount of water makes it very difficult to lift the cover slip from the slide, because the polar water molecules are able to form bonds with the two glass surfaces. The small surface irregularities in the glass increase the surface area covered by the water so increasing the tensile strength of the bond.

16.3.3 Diffusion

The diffusion theory of adhesion relies on the solubility of the materials being bonded, and is of particular relevance in packaging for bonding polymeric substances. Put simply, if two materials which are soluble in one another are brought together in intimate contact, they will form a solution at the point of contact. Instead of a separate interface between the two surfaces, which forms a third layer with its own properties, here there is an *interphase* made up of the two materials, diffused into one another. Thus there is no mismatch of properties in the bond area, no inherent stress and a very strong bond is formed. For maximum bond strength the materials being bonded (adherends and adhesive) should have the same solubility parameter.

Examples of diffusion bonding include solvent welding of plastics, where the presence of the solvent allows the polymer molecules to diffuse into one another, and when the solvent evaporates it leaves an interphase of the two adherends. Using heat (e.g. by ultrasonic welding) has the same effect, allowing the polymer molecules to diffuse into one another (www.specialchem4adhesives.com). Another example of using heat to bring about diffusion is in the coextrusion or coinjection of molten polymers to form multilayer constructions, which are virtually impossible to separate.

16.4 Adhesive types

There are various ways in which adhesives may be classified, none of which is perfect; the following types are discussed in this section:

- water-based adhesives, both natural and synthetic: these include starch and its derivatives, casein, latex (for cold seal adhesives) and synthetic emulsion systems such as polyvinyl acetate (PVA), acrylics and polyurethanes
- solvent-based adhesives, in which the carrier is an organic solvent rather than water; these include polyurethanes and acrylics (although both of these are also available in water-based formulations)
- 100% solids adhesives which have no carrier solvent; these include reactive solventless liquids and hot melts.

16.4.1 Water-based adhesives

Starch and derivatives

Like cellulose, starch is a complex polysaccharide which occurs naturally in plant matter. Commercially, the plants used are corn, wheat and potato, with some use of rice, tapioca and sago. Starch composition (e.g. amylose:amylopectin ratio) and particle size vary with source and adhesive manufacturers adjust their processes to suit. Starch granules suspended in cold water have no adhesive properties and the granules must be broken down, usually by heating in water with the addition of metal salts or caustic soda. The granules swell and at the gelatinisation temperature, which can be 50–70°C depending on starch source, burst open to give a thick colloidal suspension which now functions as an adhesive.

Unmodified starches produced in this way have low solids content and high viscosity and have to be further treated to give the stable rheological properties needed for commercial applications. Treatment with alkali lowers the gelatinisation temperature and can be used to produce jelly gums, developed in the 1950s for applying paper labels to glass bottles. Acid treatment lowers viscosity but maintains solids content; and chemical oxidation using hypochlorite improves tack. It also results in low colour which makes these starches useful in paper making (www.specialchem4adhesives.com).

One of the most common uses of starch adhesive is in the production of corrugated board. Due to the large quantity required, it is common for the corrugator to prepare the starch adhesive on site, the starch being delivered in sacks, intermediate bulk containers or tankers. Different formulations and preparation methods are used, including two-phase and single-phase, but essentially the unmodified cooked starch produced as described above is mixed with water, caustic soda and borax, and pumped to the points of application on the corrugating machine, i.e. the fluting rollers at the single facer and the point of bonding the second liner at the double backer (see Chapter 11). Typical solids content of the prepared adhesive is 20–30%. Borax is added to give the required rheological properties and it improves initial tack by causing chain branching in the starch polymer. The heat of the fluting rollers causes the starch to gelatinise immediately, forming a high initial tack which firmly secures fluting to liner. The speed of bond forming and the initial bond strength are crucial for modern corrugating machines running at speeds of 350–400 m/min. The 'green' bond continues to develop to its full strength as water evaporates from the adhesive. Cold corrugating processes are currently being developed, requiring different starch formulations (www.specialchem4adhesives.com).

Starch adhesives are ideal for bonding paper-based materials and are also used for corrugated board making and for tube winding. The raw material is relatively low cost, readily available in good quality grades and biodegradable. Also, being a thermosetting polymer, starch has good heat resistance. Various additives may be used to impart specific performance properties, such as urea formaldehyde to give good moisture resistance and polyvinyl alcohol/polyvinyl acetate to improve resistance to cold water. Biocides are also used to inhibit fungal growth.

Dextrin adhesives are derivatives of starch. The starch is depolymerised by acid and/or heat treatment and the molecules are then repolymerised to produce highly branched structures which are soluble in water, the extent of their solubility being determined by the acid/heat treatment. A wide range of dextrin adhesives is available, with different viscosities and applications, and modifications are possible using the additives mentioned above. Borated dextrins contain borax to increase tack. Dextrins generally have higher solids than starch adhesives, i.e. less water, which means they dry faster and thus support higher line speeds. As well as being suitable for bonding paper-based materials, e.g. bags/sacks and tube winding, dextrins can also be used in high speed labelling of cans and bottles.

Casein

Casein is the protein present in milk, rendered soluble by the addition of an alkali in water. Casein adhesives have an aggressive tack and are not 'stringy' in application. They can also absorb significant amounts of water without significant change in viscosity, making them suitable for high speed labelling of glass bottles and jars in cold or wet conditions, for example in beer bottle labelling. They have excellent resistance to ice water, which means that labels will not fall off the bottles in chilled conditions, but they can be removed when required, for example on returnable glass bottles, by soaking in an alkaline solution. However, casein is a high cost raw material which is becoming more expensive, and alternative casein-free options are now available for the beverage sector. These include water based starch formulations modified with various polymers and resins, as well as wholly synthetic alternatives (www.specialchem4adhesives.com).

Animal glues

Animal glues are also protein adhesives, derived from bones, skin or blood and many ancient artefacts in museums testify to their long time usage. They are mostly solid at room temperature and are dispersed in water to give the required solids content and applied at a slightly elevated temperature by a roller/doctor blade, though they may also be jetted. Initial tack occurs as the temperature drops below the gelling point, typically 25°C, and then a final bond forms as water evaporates. Although largely replaced by starch or synthetic alternatives, some animal glue is used in rigid box making and fancy box covering.

Latex

Natural rubber latex is commonly used in the production of cold-seal adhesives, which are widely used in confectionery packaging. Early pressure sensitive adhesives were also based on natural rubber latex but have largely been replaced by acrylates. Latex has the interesting property that it adheres relatively poorly to any material other than itself. When a water-based latex adhesive is applied to a polymer film, and dried to remove the water, the resulting coating is non-tacky and thus the film can be reeled up. On the packaging line the film is unwound and wrapped around the product (typically on a horizontal flow wrapping machine) and the latex-coated surfaces will seal to each other simply by the application of pressure. No heat is required, which allows for high speed wrapping and there is no deterioration of heat sensitive products such as chocolate. The cold-seal coating is usually applied in a pattern by gravure printing, to match the sealing areas, although this can lead to winding problems due to the uneven layers. Offsetting onto the printed side of the web is another potential issue.

As well as natural rubber latex, formulations may also include plasticisers to improve flexibility, resins to improve tack and bond strength, and antioxidants to limit oxidation of the rubber, as well as other ingredients. Blends of latex and copolymers such as ethylene vinyl acetate are also being used as cold-seal adhesives. Concern about allergies associated with natural latex has led to the development of synthetic alternatives.

Polyvinyl acetate (PVA) and ethylene vinyl acetate (EVA)

These synthetic water-based emulsion adhesives are the well-known ‘white glues’ used throughout the packaging industry for applications such as carton side seaming, carton closing, bag making and many other uses. Strictly speaking, they are dispersions rather than emulsions, in which the insoluble polymers (the dispersed phase) are uniformly distributed in water (the continuous phase). This uniform distribution is brought about by using a protective colloid which effectively surrounds the solid polymer chains and holds them in a stable state in the water carrier. Suitable colloids include hydroxyethyl cellulose and polyvinyl alcohol, which also has surfactant properties, providing stable formulations with good wettability. Solids content is 50–70% and thus these adhesives are faster drying than starch and dextrin. After application, once sufficient water is removed, the emulsion 'breaks' and the polymer rapidly forms an adhesive bond. This 'green' bond should be sufficient to hold the substrates in place and it will continue to develop as more water is evaporated.

PVAs and EVAs are ideal for use with cellulose-based substrates which readily absorb the water carrier. They are widely available in formulations for a range of applications, are easy to apply using conventional roller or jet applicators, and application equipment is easy to clean. They must not be allowed to freeze in storage, as this will cause separation of the solid and liquid components.

Acrylic

Acrylic adhesives are available as water-based emulsions and can be formulated to meet a diverse range of applications such as: wet bond lamination of polymer film to paper and board; dry bond lamination of polymer films; and pressure sensitive labels and tapes. They are relatively low cost adhesives, with low odour, based on acrylates such as 2-ethylhexyl acrylate or iso-octyl acrylate and can be crosslinked for improved heat or chemical resistance. They tend to be especially useful for bonding low surface energy materials such as the polyolefins. When used for cellulose-based substrates, their low water content avoids excessive wetting and hence swelling of the fibres compared with PVAs. Crosslinking formulations used in lamination develop a good initial bond on application and heating, and then the crosslinking reaction continues in the reel during storage at ambient temperature.

In the pressure sensitive sector, acrylic adhesives can be formulated to provide removable or permanent properties. UV curable urethane acrylate solvent-free systems are also available. Vinyl acetate acrylic copolymers are being used in adhesive formulations and are claimed to have excellent strength. Again, they allow a high degree of formulation latitude and can be made into stable emulsion systems suitable for film lamination or pressure sensitive coatings for labels and tapes (www.specialchem4adhesives.com).

Polyurethane

Water-based polyurethane adhesives are available for film laminating and have excellent adhesion properties with a range of different substrates. They are based on polyesters and isocyanates and, like acrylics, can also be crosslinked, with the majority of the crosslinking taking place in the reel during storage. They are more expensive than acrylates but may be more appropriate if heat resistance is important, such as hot-fill applications.

16.4.2 Solvent-based adhesives

Adhesive systems using organic solvents as the main carrier were much more widely used in the past than they are now, due to increasing environmental and health and safety concerns. Over the past 10–20 years these concerns, plus legislation limiting the emission of volatile organic compounds (VOCs) into the atmosphere have encouraged user companies and adhesive formulators to seek alternatives. These alternatives fall into two main classes: water-based formulations (e.g. acrylics and polyurethanes as already discussed) and 100% solids solventless systems, which will be discussed below.

When comparing solvent- and water-based systems, the latter will almost always take longer to dry than their solvent-based counterparts, thus requiring more energy and possibly resulting in reduced line speed. These factors should be taken into account when comparing environmental impact and operating costs. It is also worth noting that water-based formulations are not necessarily organic solvent free, and thus VOC emissions may still present a concern. With regard to performance (specifically bond strength), water-based adhesives are generally regarded as less effective, although this is a very broad generalisation and performance must be evaluated for each end use; it is quite feasible that while a water-based adhesive may provide a weaker bond than a solvent-based version, that bond may be sufficient for the job required.

Solvent-based adhesives still have a role to play, for example polyurethanes as dry bonding adhesives for retortable pouch laminates, which have to withstand high temperatures for extended time periods, and pressure sensitive acrylics and high solids content styrene block copolymers for some specialist tape and label applications. Converters using solvent-based adhesives are likely to have to install solvent emissions abatement systems, at high capital investment, to comply with legislation.

16.4.3 100% solids adhesives

Solventless adhesives

Solventless adhesive systems come into this category, many developed in response to the requirement for reduced solvent usage and emissions, referred to above. Many are based on polyurethane chemistry using isocyanates and can be one-part or two-part systems. For film lamination, one-part systems rely on moisture to promote cross linking after the adhesive has been applied to one substrate and nipped to the second substrate, which means storing the reels until the adhesive is cured before slitting and packing to the customer's requirements. The extent of crosslinking depends on the moisture available and is not always consistent. Two-part systems allow better control, provided metering of the two components is accurate, and mixing is efficient. However, once mixed, the adhesive will start to set and this can give operational issues on the laminating equipment, reducing the appeal of these systems (www.specialchem4adhesives.com).

Developments in formulation now allow more rapid crosslinking and thus bond integrity, reducing the waiting time before slitting. Urethane acrylate systems cured by ultraviolet (UV) or electron beam (EB) are also available, both for laminating and as pressure sensitives for labels and tapes, allowing high production speeds without damaging heat sensitive substrates. Isocyanates are toxic and must be handled with care in the workplace, and the development of non-isocyanate solventless polyurethanes may have some applications in flexible packaging and pressure sensitives. A general property of polyurethane adhesive systems, either solvent-based or solventless, is that they are thermosetting and thus have good heat resistance in use.

Hot melts

Hot melt adhesives account for the major part of the 100% solids solventless sector, and are used for a wide range of applications both by converters, for example pressure sensitive coatings for labels, heat-seal coatings for lidding and film lamination; and packer-fillers, for example closing of paper bags and sacks, cartons and cases. Formulation options for hot melts are wide and depend on end use, for example styrene block polymers can be used for pressure sensitives, and polyolefins such as polyethylene, ethylene vinyl acetate and polypropylene can be used for coating and laminating, as well as for the packer-filler end uses noted above. Being based on thermoplastics, obviously hot melts do not offer heat resistance in use. As well as the base polymer, hot melts also include tackifying resins, waxes to lower viscosity, antioxidants to inhibit polymer chain breakdown and stabilisers to reduce deterioration due to heating.

In the packer-filler sector, hot melts are usually delivered cut or extruded into small pieces to allow for easy melting in a holding tank. The liquid adhesive is delivered via heated carrier hose to the applicator, which can be a dauber, wheel or jet. Application temperatures vary from around 170°C to around 100°C for 'warm melts'. The main advantages of hot melts are that they are generally fast setting, allowing high production speeds, and they have good gap filling properties, useful for rough surfaces. However, they require continuous energy to keep them in the molten state during application, which is a potential health and safety hazard as well as an economic consideration. If overheated they may be prone to degradation which can result in unacceptable levels of odour and taint or even contamination with charred fragments. Also, as already stated, they are not suitable for use in high temperatures.

16.5 Selecting the right adhesive

As can be seen from the previous section, there are several adhesive options available for different end uses and thus selecting the most appropriate adhesive is not always straightforward. The best approach to this task is to regard the adhesive in the same way as any other packaging component, and consider the key functions of the finished pack (refer to Chapter 3) and what part any adhesive(s) will have to play in meeting those functions. The pack design and development process (Chapter 18) starts with a brief and involves the consideration of options for meeting that brief; these options should always include the adhesives, i.e. adhesives should be considered at the start of the process and not left to the stage of final specifications. It should be clear by now that knowledge of substrate properties is essential when selecting adhesives, as well as a thorough understanding of the conditions to which any adhesives bonds will be exposed throughout the life of the packaging components and the finished pack.

16.6 Adhesive application methods

Adhesives are applied by a variety of methods, which can be divided into those in which the adhesive covers the entire surface of the substrate, and those in which only certain areas are coated with adhesive. Broadly, the former are more likely to be part of the converter operation and the latter part of the packer-filler activities, although these are not exclusive categories and there are exceptions.

Laminating adhesives for film and paper structures are generally required to be applied over the entire substrate surface, as are pressure sensitive adhesives applied to label stock, and heat-seal coating applied to lidding stock. Coating methods include roller coating, blade/knife coating, flexo roller and gravure cylinder. Critical factors are the deposition of an even coating, at the correct weight, and adequate drying/curing of the adhesive, especially when laminating impermeable substrates because of the potential risk of trapping 'wet' adhesive between the substrates, which would lead to poor adhesion and odour problems.

Cold-seal coatings are applied as part of the converter operation, but are most often applied in a pattern to coincide with the pack sealing points, rather than being applied all over. Gravure cylinders are normally used for this, although current developments include formulations which can be applied by flexo plates.

Many packaging line operations involve the application of adhesive to the closure part of a filled pack, e.g. end flaps on cartons and cases, and folded sections on paper bags and sacks. Such operations involve applying the adhesive to a designated part of the pack and this is achieved by means of daubers or jet systems. Again, a critical aspect is the application of just the right amount of adhesive: too little and the bond will be weak, too much and the line speed will have to be reduced to allow time for drying, as well as being a waste of money and resources. Another problem associated with using too much adhesive is that the excess can be squeezed out away from the seal area, causing packs to stick together later in the process. Accuracy of application is also critical, so that the adhesive is in the correct place in relation to the alignment of the two substrates.

For all adhesive operations, cleanliness is important. This applies to substrates (dirt can impair wetting out) and to adhesive reservoirs, delivery systems and applicators such as jets. All possible steps must be taken to prevent contamination, whether by dirt or any other foreign bodies, and also by other adhesives. Adhesive manufacturers generally formulate their products to work 'as is' and it is not advisable to interfere with them by adding other materials. Recommendations on application temperature should be followed closely; the temperature of an adhesive will affect its viscosity, which in turn determines how much is applied. The temperature and humidity of the operating environment are also important.

16.7 Evaluating adhesive performance

Probably the most relevant parameter to check on any adhesive bond, both during pack development and as an on-going quality check, is the bond strength, and there are two aspects to this: firstly, the resistance of the bonded substrates to being peeled apart, and secondly, their resistance to the application of a shear force. The former is more likely to be of use in packaging applications, but both are mentioned for completeness.

Peel strength can be measured using a tensile tester or similar device; essential requirements are a means of clamping the two substrates of the test sample and a means of applying a consistent force to peel the adhesive bond apart. Sample dimensions, speed of peel and environmental conditions of temperature and humidity will all affect the result obtained and thus for accuracy must be standardised. International standards exist, such as the American Society for Testing and Materials (ASTM) International which specify test conditions. Another factor which affects the measured peel strength is the angle of peel and the choice of test should reflect the most likely in-use conditions.

Test options are:

1. T-peel, in which each substrate is clamped vertically in the jaws of the tensile tester, e.g. ASTM D1876-08.
2. 90° peel, in which one substrate is pulled away from the second substrate at an angle of 90°, e.g. ASTM D6252-98(2001) (note that this is a quality assurance test method specially for pressure sensitive labels).
3. 180° peel in which one substrate is pulled back on itself away from the second substrate, e.g. ASTM D903-98(2010).

A practical approach may be to use ASTM or other test methods as the basis of a test programme, introducing modifications to mimic actual use, provided the conditions used are consistent from test to test. This could apply when evaluating alternative adhesives for a given application, and when carrying out regular quality checks on the packaging line. One of the difficulties associated with the latter is that the bond is unlikely to have reached its full strength during the packaging operation and this is especially the case with water-based adhesives. However, it is still possible to set a standard for on-machine bond strength. In addition to the adhesive bond strength, other properties of bonded substrates which may be evaluated at the development stage include temperature resistance, odour and colour.

16.8 Troubleshooting adhesive problems

As has already been noted, adhesives generally work in harmony with specialist equipment, and the equipment will have certain requirements with respect to viscosity, running characteristics, tack and open time. For example, on a high speed carton closing line, a hot melt adhesive may be applied to the flap of a carton, the flap is folded to close the carton and the adhesive bond is held under light compression for a period of time. Closed cartons are then automatically packed into outer cases which are then palletised. There are several demands which the adhesive must meet, in addition to the obvious one of being compatible with the carton and its intended end use. It must remain open or active until the flap of the carton is closed; it must then develop a sufficiently strong bond so that when the compression is released it does not spring open; and the bond at that stage must be strong enough to withstand the rigours of the casing and palletising processes.

If any of the operating parameters moves substantially away from the optimum conditions, the bond strength will be impaired and ultimately the pack can fail. For example, a failure in the upstream process (such as a delay in filling the cartons) which necessitates reducing the line speed, albeit for a short time period, may mean that, by the time the carton is closed and under compression, the adhesive has already lost its tack, i.e. it will no longer form a bond. If the speed of the packaging line is increased for some reason, the bond may not be developed sufficiently when compression is released, resulting in the carton springing open. Even worse, the pack may retain a certain percentage of the bond strength, so that the failure only becomes apparent once it is in the storage and distribution environment, including on the retailer's shelf.

All automatically applied adhesives will have the same issues. They are typically designed to work within certain parameters and, particularly when troubleshooting, attention should always be paid to any changes that may have been made to the operation of the packaging line. Any planned changes to the operation of the packaging line should be made with reference to the adhesives manufacturer, who will be able to advise on any required modifications to the grade of adhesive in use.

Faced with what appears to be an adhesive failure, the first step is always to examine the adhesive film. Adhesives fail in one of two ways, cohesively and adhesively. A cohesive failure is a failure of the adhesive film itself, while an adhesive failure is the failure of the adhesive to stick to one or other of the adherends. An immediate indication of which of these the packaging technologist is faced with is to examine the adhesive film. If it is 'shiny', with no visible fibre tear from the adherend, then it is likely that the problem is one of adhesion. If there is adhesive on both sides of the joint, then it is most likely that the adhesive film itself has failed, which is a cohesive failure. There is a further failure mode, evidenced by the surface of the adhesive film being covered by fibres from the adherend. This is a failure of one or other of the substrates, not the adhesive.

It is important to note that an adhesive 'failure' may just be a symptom of a change in the packaging process, and therefore the first question to ask is 'what has changed?'. There should be a record of operating parameters on the production line, and these should be checked to identify whether any modifications have been made. This does, of course, assume that the packaging line has previously been running trouble-free.

16.9 Common adhesive terminology

Many of the following terms are to be found on adhesive date sheets:

- *Closing time or setting time*: This is the time during which the adherends and adhesive must be in intimate contact such that the bond is sufficiently secure that it will withstand subsequent handling. In most packaging operations, this is determined by the layout and speed of the packaging line.

- *Coating weight*: This is the amount of adhesive applied, usually quoted as grams per square metre. Adhesive manufacturers often recommend typical coating weights for given applications. Applying too little means inadequate bond strength and applying too much is costly and may lead to an open time that is too long for the machine and bond failure.
- *Cohesive strength*: This is the strength of the adhesive film itself. Once the adhesive film has formed, the bond can still fail because the polymer is not strong enough. A self-seal envelope and a cold-seal bond on a confectionery wrapper are both examples of bonds where the adhesive strength is higher than the cohesive strength of the adhesive film.
- *Fibre tear*: This applies only to bonds involving paper and board. A good bond is one which, when an attempt is made to peel it apart, results in tearing of the cellulose fibres, i.e. the adhesive is stronger that the inherent strength of the paper.
- *Green bond*: This is the bond achieved prior to drying or curing of the adhesive.
- *Open time*: The maximum amount of time between when an adhesive is applied and when the substrates can be brought together and still make an effective bond. This varies from a few seconds in the case of many hot melt adhesives to several minutes with some PVA or EVA types.
- *Solids (non-volatile) content*: The percentage of the adhesive which will remain once the carrier has dried off. For example, a hot melt adhesive is described as 100% solids, because it moves from a liquid to a solid state without losing any of its content. A PVA water-based emulsion is typically around 50% solids, so the volume of the final adhesive is half of the volume of the adhesive as applied. When calculating adhesive costs, it is important to take solids content into account.
- *Tack or grab*: The property of an adhesive which enables it to form a bond of measurable strength (the 'green' bond) immediately after the adherend and adhesive are brought together under low pressure (ASTM). If it is desirable to reposition one substrate after forming the bond, an adhesive with a lower tack will be required.
- *Viscosity*: Viscosity is a measure of resistance to flow. It must be appropriate for the method of application being used so that the correct coating weight is applied consistently.
- *Wetting out*: The ability of an adhesive to spread across the surface of an adherend such that it forms a bond with it; failure to wet out will result in uneven bonding.

16.10 Sources of further information and advice

As adhesives are so widely used in many industries, finding sources of information specific to packaging applications can be difficult. One highly recommended web-based source used to inform the writing of this chapter is www.specialchem4adhesives.com. This is free to access after registration and has an easy-to-use search facility which identifies articles of both technical and market relevance, as well as patents and data sheets.

Market information is often available from trade associations, such as:

- The British Adhesives and Sealants Association: www.basaonline.org
- The Adhesive and Sealant Council (North America): www.ascouncil.org
- FEICA, The Association of European Adhesives and Sealants Manufacturers: www.feica.com

Useful textbooks are:

- Petrie, E. 2007. *Handbook of Adhesives and Sealants*, 2nd edn, McGraw-Hill, London.
- Pocius, A.V. 2002. *Adhesion and Adhesives Technology*, 2nd edn, Hanser, Munich.

17
Labels for packaging

A. R. WHITE, AWA Consulting, UK

Abstract: This chapter discusses the importance of the label in the packaging process. The different types of labels are outlined along with trends in types of labels and the substrates used. Basic specification requirements are listed. The market for labels and the opportunities for the future are mentioned.

Key words: self-adhesive, markets, trends in labels, uses of labels, sleeves.

17.1 Introduction

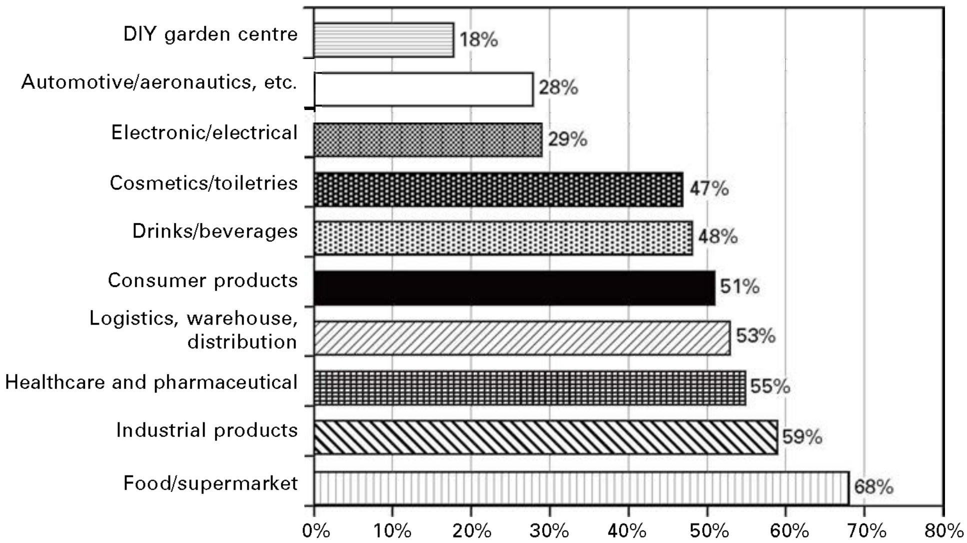
Labels are an integral part of the packaging industry and have been for well over 100 years. In the early days they were simple, handwritten and used for identifying bales of cloth by batch and colour. Their use spread quickly and nowadays they are used in a variety of ways and applications.

The label is a versatile tool with the basic function of providing information, be it brand recognition, legislative information, as a selling tool or for many security applications. The most important information which a label can contain includes weight, usage instructions, hazardous warnings, etc. Labels are produced in many shapes and sizes often with focused, defined characteristics as we will see later in this chapter.

Wherever you look, labels are in evidence. A trip to the local supermarket will reinforce how important the label is to product recognition and thereby to the selling function. Look at the many bottles, jars or cartons which use the humble label. The end use markets (consumers) for labels include food, pharmaceutical, cosmetic, industrial, wine and spirits etc. (see Fig. 17.1), each requiring specific characteristics, e.g. resistance against chemicals, abrasion, freezing, water, etc. In addition to normal labels, derivatives include in-mould, sleeves and pouches. 'Smart' labels are able to indicate the freshness of a food product, some can provide oxygen scavenging properties, while others offer anti-counterfeiting measures and tamper evidence. They can even be applied directly onto fresh food products like apples, oranges and bananas.

An expanding and developing market is the use of RFID (radio frequency identification) tags which are becoming more widely used as they are becoming cheaper to produce. These tags are used in a variety of tracking and security applications, e.g. libraries, retails shops and for tracking products through a supply chain. They will gradually replace bar codes for pricing and promotional campaigns.

When all the information required cannot be contained on a single label, multi-page labels can be produced which may be used to supply information in several



17.1 Main end user sectors for labels (M. Fairley, Tarsus Group Ltd).

languages or the many contra-indications required in the pharmaceutical industry. A very recent application is the provision of Braille characters which has become a mandatory requirement on all retail medicines.

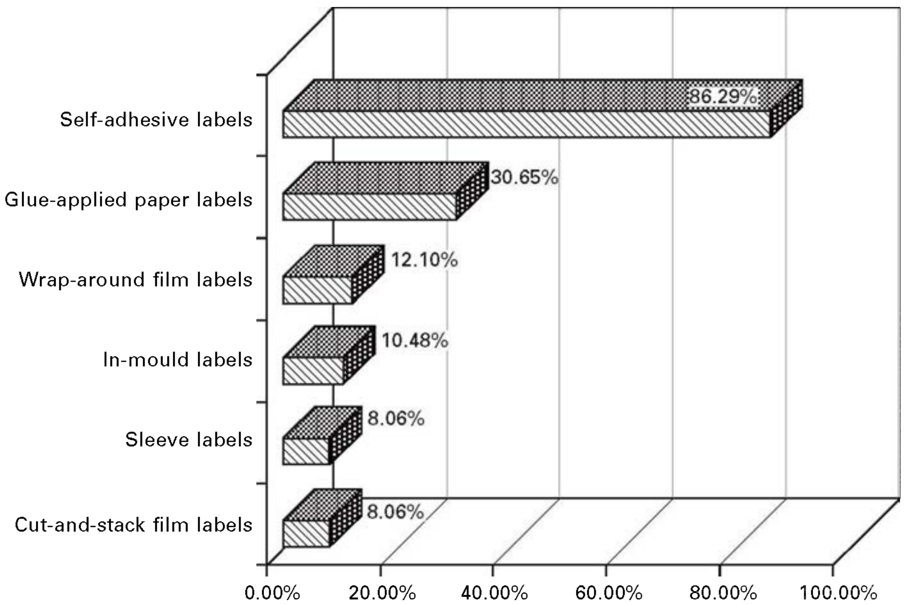
Although label purists would say that shrink sleeves are not part of the label world, they do play an important role in decorating bottles which are an unusual shape and they are, in general, manufactured using a narrow web press.

17.2 Trends in label types

For the first half of the twentieth century glue applied labels were the only method of application, until the 1950s when Stanton Avery 'invented' the self-adhesive (pressure sensitive) label. Figure 17.2 shows the current usage of self-adhesive labels compared to other types of labelling techniques. In-mould labels and sleeves now feature prominently in the label industry.

17.3 Self-adhesive (pressure sensitive) labels

This type of label is now by far the most popular and has taken a significant market share from wet glue applications during the past 10 years. They can be used in a wide range of applications as they can be applied to the product more quickly and can be printed on many different substrates. With modern printing presses and finishing equipment, very fast changeovers from one design to another can be achieved quickly and easily.



17.2 Types of labels produced by European label converters (M. Fairley, Tarsus Group Ltd).

17.3.1 Label production

In general, self-adhesive labels are produced on a roll-to-roll press for efficiency and supplied finished, ready for application to a product using a fast label application machine.

The label face material, which can be paper or a film composite (there are more than 1,200 different face materials available that can be used in label production), is provided in roll form with an adhesive on the back. It can be printed using several printing techniques although there are still labels which are provided with no printing on initially. For visual effect, the finished label can be laminated or varnished.

In order to stop the material sticking to itself, a backing sheet or liner is used which is discarded when the label is applied to the product. The composition of the liner is very important as it must have enough tack to keep the label on the liner yet release it easily when it is applied to the pack or container. A silicone coating is the normal means of preventing the label sticking to the backing sheet.

When the label is printed, it is usually cut to shape using hardened metal dies which can be in a flat bed or rotary configuration. Laser cutting technology is gradually replacing metal dies as it is faster and can be adjusted to the desired shape of the label much quicker and it is easier to produce complicated designs. An important factor in die cutting is that the die must only cut through the face stock and not the liner otherwise, when it comes to the application stage, the liner would come away with the actual label.

When the label has been printed and die cut, the finished label is separated from the selvedge or waste (the skeleton which is the area not required for the actual label) and wound up ready for use on the labelling machine, the waste being collected for disposal or recycling if possible.

17.4 How a label manufacturer approaches a job

Once the label manufacturer has determined the end use for the label, he will purchase the label stock to the correct specification, already coated with the appropriate adhesive on the back and the liner in place. It is then printed on the face material with the required design in exact register, not only with the multiple colour images but also the die cutting position. During the production run the label is cut to shape in line by means of a rotary (usually) cutting die which, as already mentioned, must be carefully set so that it only cuts through the face material and the adhesive, and not the silicone layer or the carrier web. If this happens the web can break during label application, causing downtime and loss of product. Labels may be butt-cut, with no space between each one on the carrier web or, more frequently, die cut to a specific shape with a defined space between each label.

Labels for semi-automatic and automatic application are invariably required to be spaced on the carrier web, as determined by the requirements of the application machine. Labels are normally supplied on reels.

17.4.1 Label substrates

Paper was the first material used for self-adhesive labels and is still widely used. Factors governing choice of paper will be covered in Section 17.5.

Plastic films are being used to great effect as they offer a wide range of extra benefits over paper. Some of the reasons are outlined below.

- The wide range of aesthetic effects available: gloss, matte, opaque, transparent, pearlescent.
- More effective recycling opportunities by using one type of plastic for the whole product enclosure, e.g. a polypropylene label on a polypropylene bottle also fitted with a polypropylene closure.
- Only plastic films can offer a ‘no label’ look on transparent containers such as glass and PET bottles. This type of label is becoming increasingly popular especially for spirits and water bottles. The total cost is much less than decorating the bottle (usually glass but not always) by any other means. It also means that one type of bottle can be utilised for a wide range of products simply by changing the label. This reduces storage space requirements for incoming packaging materials and enables a more cost effective solution to be offered for the filling company.
- Plastic films are more durable and versatile than paper in moist conditions such as bathrooms and kitchens.
- Plastic films offer improved product resistance where there is likely to be product spillage down the sides of the container and/or the product is likely to be handled in dirty or damp conditions such as garages and gardens.

(The performance of paper in the last two cases can, however, be improved by surface lacquering or film lamination.)

17.4.2 Adhesive selection

As well as selecting the most desirable face material for a given end use, it is also necessary to select the correct adhesive from a range of standard options. Selection criteria are based on the requirements of the substrates and the performance expected from the final product, including a consideration of whether or not the label is meant to be a permanent feature of the pack. A label applied to a pharmaceutical product is almost certainly required to be permanent, whereas an information label on a decorative tin of biscuits may be designed to be peelable so that it can be removed when the initial use is complete. Self-adhesive labels are available in permanent and peelable options, as well as water removable for reusable containers or recycling purposes. Depending on the storage conditions of the product and the substrate to which the label is applied, even peelable labels can be difficult to remove over time and so-called permanent labels can peel off.

17.4.3 Label application

Self-adhesive labels are normally applied by semi or fully automatic labelling equipment, depending on the speed required. In fully automatic systems, the label applicator is an integral part of the packaging line and speeds in excess of 600 packs per minute and more are possible. A sensor detects the presence of the item to be labelled, causing the label to be automatically dispensed from the backing paper. The label is picked up by direct contact with the item, or blown on (common in the application of top 'saddle' labels). The label is then wiped firmly onto the container to ensure full adhesion with the substrate.

Fully automatic systems require special tooling known as a 'beak' which is specific to the label dimensions and shape. The purpose of the beak is to fold the carrier web back on itself, allowing the adhesive-coated edge of the label to be exposed, ready to be picked up by the container. The carrier web is wound up separately and disposed of using specialist disposal contractors.

17.4.4 Storage requirements

Self-adhesive labels should be used (once printed) within a reasonable period of time after their manufacture, preferably not more than six months depending on storage conditions. There are two reasons for this: firstly, the adhesive tends to bleed slightly around the die-cut edge, which means that adhesive can offset onto the back of the release paper, which will cause unwinding problems on the application machine. This is made worse by storing the reels of labels in warm conditions. Reels must always be stored horizontally on the flat, cut edge and never on the face. This applies to part reels removed from production as well as to new material from the supplier, which should be left in its individual reel wrapping and stored in cool, dry conditions. A second potential problem associated with long-term storage is that, like any reeled material, the labels can take on a permanent curvature, which becomes more pronounced towards the core. This can lead to the label not standing out sufficiently from the beak to be picked up by the container at the point of application.

17.5 Wet glue (gummed labels)

This type of label can be produced on paper or film and, in general, requires the application of an adhesive to allow it to be attached to a product container. This technique has enjoyed widespread use (and still does in some areas) in fixing labels to bottles, primarily in the beer and spirits markets. They used to be used almost exclusively for wine bottles, but in recent years this market has given way to self-adhesive labels. They are still used widely for wraparound labels on canned goods and some soft drinks applications.

17.5.1 The application of labels to the product

The labels are normally pre-printed and delivered to the filler machinery in stacks, pre-cut to the right shape and dimension. A stack of labels is placed into a magazine on the filling machine and a label picked from the stack using glued pickers or vacuum transfer over a glued roller, and then applied to the container. The container must be firmly gripped to prevent excessive movement which would result in mis-applied labels. The label is wiped onto the container with rollers or brushes. For wraparound labels on cylindrical containers (e.g. cans), a line of adhesive is applied to the can and this acts as the pick-up mechanism for the label. The can rotates to wrap the label around the surface and a second line of adhesive is applied to the overlap. The usage of adhesive is thus kept to a minimum which also makes the label easier to remove for recycling.

17.5.2 The choice of substrate

Printed paper is the most economical choice for labels for canned goods, while beers and spirits are more likely to be labelled using film laminate structures, aluminium foil/paper laminates or metallised paper. Embossing and foil-blocking are good ways to add visual effects to a label and give a wide range of special effects.

The selection of suitable papers for ungummed (and other) labels is dependent not only on the aesthetic effects required but also on the environment in which it will be used. For example, if the label is to be used in freezing conditions then the label must stay on the container until it is defrosted and the contents used. Some might require resistance to scuffing, others to being re-wet constantly as in shampoo bottles. The economics of producing and placing a label on a product can be an important feature of the whole production chain.

Papers can be clay coated for surface smoothness and opacity giving high quality finishes suitable for high quality printing processes. Where this is not important a lower, cheaper grade of paper can be chosen. As with all other packaging materials, the packaging technologist should seek out the most cost effective solution, commensurate with meeting all the other requirements of the product pack.

Paper selection is also governed by the label application method to be used. For instance, where a vacuum pick-up is to be used, the paper's porosity to air is important as is the degree of stiffness with regard to application to tightly-radiused surfaces. Where the curvature of a container is tight, a lightweight, flexible label is easier to apply – and more likely to remain in place – than a heavier weight, stiffer material. Moisture absorbency (measured by the Cobb value) will affect the speed of wetting out of the adhesive and thus the speed of application.

An important property of paper in its use for labels is its degree of curl. When paper is wetted during the application of ungummed labels, the fibres swell due to the absorption of water, the degree of swelling being greater in the cross direction than the machine direction which causes the paper to curl parallel to the machine direction, away from the wetted surface. The effects of paper curl can be minimised by the choice of paper and by keeping the amount of water used in the adhesive application process to a minimum. The grain direction required should always be specified to the supplier. Usually, but not always, the grain direction is parallel to the base of the label.

Wraparound labelling of PET bottles for soft drinks uses paper or plastic labels, the latter providing better flexibility on the flexible bottle, less wrinkling due to moisture absorbency and good aesthetic effects. Other benefits of plastic versus paper are improved scuff resistance of the print (by reverse-printing the label) and resistance to tearing and damage during use. Plastic film labels on bottles destined for refilling are more easily removed intact than paper labels, which are likely to disintegrate in the cleaning process leaving a slurry which is difficult to clean out.

A wide range of materials is used in the label market. Paper substrates are by far the most popular followed by plastic films as shown in Fig. 17.3. Film labels are usually supplied on the reel, which eliminates the cutting stage during label production and are easier to handle and are less prone to damage than stacks of cut single labels. A cutter on the label applicator cuts the label to size as it is applied.

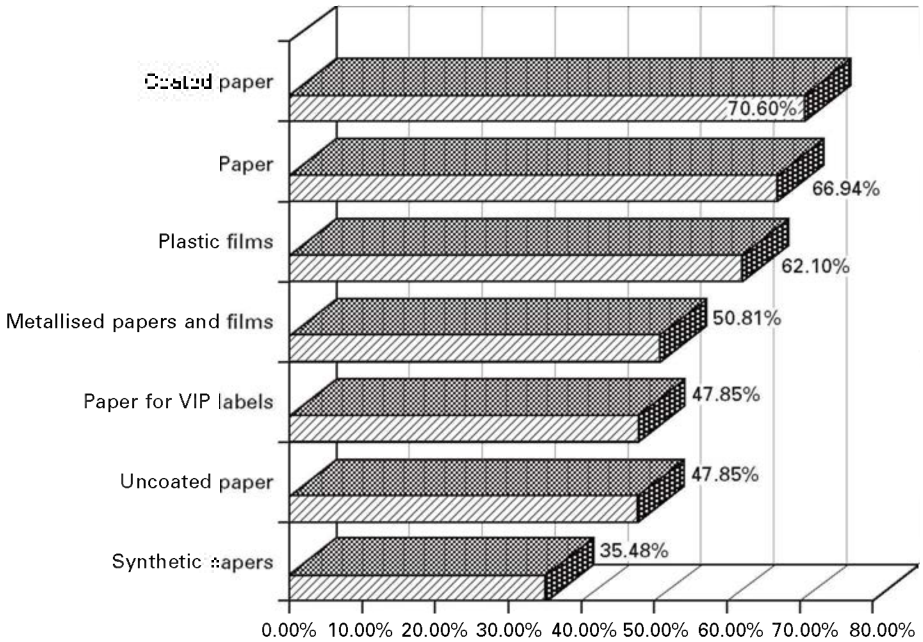
The major uses of ungummed labels are in the high-speed bottling of drinks and canning of food. Machines with application capabilities up to 100,000 containers per hour are available.

17.6 In-mould labels

In-mould labels are applied to a container during the manufacturing process. A pre-printed label is placed in the mould and the label becomes an integral part of the finished item, with no requirement for label application equipment on the filling line.

In-mould labelling (IML) is carried out on blow mouldings such as polyethylene and polypropylene containers or bottles. The label substrate can be paper, in which case it is coated with a heat sensitive adhesive, or films such as polypropylene which fuse directly to the blow moulded container.

In-mould labelling of injection mouldings most commonly uses film labels,



17.3 Main types of materials printed or converted (M. Fairley, Tarsus Group Ltd).

which are placed into the injection mould. The molten plastic is injected and the label fuses to the component surface. Good, all-round decoration can be obtained using this method, which is currently used for tubs for butter and margarine, and for large containers for biscuits. A similar process exists for in-mould labelling during thermoforming.

The pre-printed and die-cut labels are delivered to the moulder in stacks and are usually picked up and placed automatically into the mould during the opening cycle. Accuracy of label placement in the mould is critical for good finished effects.

IML offers high quality printing (film labels are printed by gravure or flexographic processes), over a large surface area, with excellent adhesion and resistance to scuffing.

17.7 Sleeves

Shrink sleeve labelling is a relatively low volume but fast-growing sector of the market, offering all-round decoration of a container, scuff resistance (by printing on the reverse side of the film) and the option of tamper evidence, by extending the sleeve over the closure of a container. Shrink sleeves are also used to combine two packs together as one sales unit, often as a promotional offer. Where tamper evidence is required, it is usual to incorporate a tear-strip (either as a separate tape, or by the use of two lines of vertical perforations) to gain access to the closure, and horizontal perforations around the sleeve to avoid removing the entire label when opening the product.

Shrink sleeves are made from a flat web of plastic material, usually PET, OPP or PS. PVC has been used in the past and has good shrink characteristics, with minimal distortion at low temperatures but has some environmental issues. Therefore PET and OPP are gaining market share. PET shrinks very quickly and requires tight control of the shrink tunnel temperatures to avoid distortion. OPP shrinks more slowly, requiring a longer dwell time.

Shrink sleeves are normally utilised in the following way:

1. The film is printed and then formed into a sleeve and welded.
2. Sleeves are delivered to the user either pre-cut for manual or semi-automatic placement over the container, or in reel form for automatic cutting and application on the filling line.
3. After placement the sleeve must be located in position on the container which is done either manually or by rotating flails or bristles.
4. The loosely sleeved container is then transferred to a shrink tunnel which may use hot air, radiant heat, or steam to apply heat to the sleeve to shrink the label onto the container in the correct position. The direction of the heat onto specific areas is important to provide an even and correct level of shrinkage without excessive distortion.

17.8 The choice of printing process

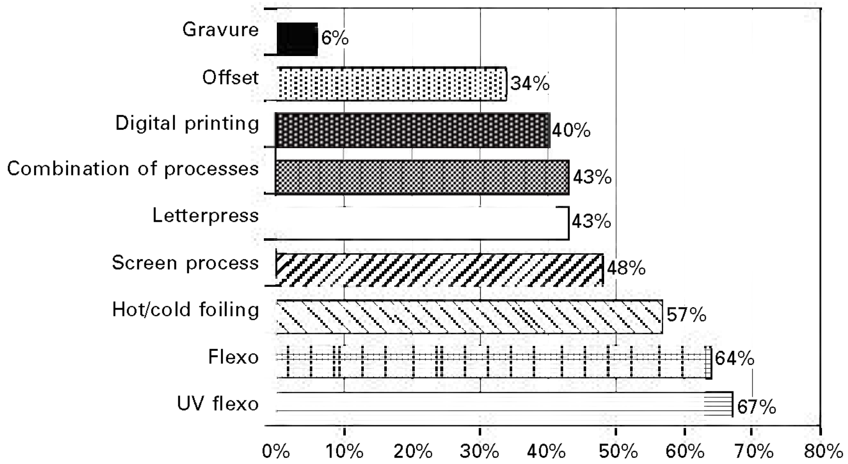
The choice of the printing process to produce a pre-printed label will be largely determined by:

- quantity of labels required
- finished quality required
- limitations of the label type
- whether the copy is fixed or variable (e.g. price/weight information).

Labels may be printed by rotary letterpress, flexo, gravure, screen or litho, depending on quantity and quality requirements, and may be foil blocked and/or embossed for special effects (Fig. 17.4). The use of digital printing for labels is expanding rapidly, as it enables the brand owner to enter a market with the minimum of waiting time and minimises development costs. 'Spur of the moment' promotional campaigns can be mounted quickly in response to changing market conditions. Shrink sleeves are printed in the reel prior to tubing, using flexography or gravure.

Ink jet printing is an 'on demand' process which is more commonly used for on-line printing of date codes, 'best before' data, batch identification, etc., directly onto packaging components such as tins and bottles. This application is not considered to be high quality, as the main consideration is that the information is legible. It is a non-contact process, with special ink being dispersed into very fine droplets through a nozzle, giving the familiar dot matrix appearance.

Printed labels can be dated, coded and given variable information by ink jet printing, in which case, if the label is lacquered, an area must be left unlacquered for satisfactory adhesion of the ink droplets. On high-speed lines where the capital



17.4 Printing processes used (M. Fairley, Tarsus Group Ltd).

cost can be justified, laser printing of additional information can be carried out. The laser effectively etches the printed surface, leaving the label substrate exposed.

17.9 Label specifications

Printed labels must meet all the requirements of any printed surface for a particular application, such as resistance to fading, scuffing, specific products, etc. They must be easy to read under the normal usage conditions within which the product is used. This must be a prime consideration at the design stage. Bar codes must be guaranteed to be readable at the point of sale and at any other relevant points in the distribution process, and should be verified at some stage in the production cycle.

Label dimensions, reel dimensions, core dimensions and unwinding direction must be specified before the label is printed to allow the maximum compatibility with the downstream operations. Reels should be carefully wrapped to protect them from damage during transit to the filling machine. Storage conditions should be carefully monitored to ensure that the labels arrive in good condition ready to be used and to minimise excessive waste.

Labels must meet all the service requirements of the final product and have good adhesion to the relevant surface on which it will be mounted. Any particular requirement must be met during the useful life of the product, e.g. a shampoo bottle (continual wet and damp conditions), tinned vegetables (long shelf storage), etc., and finally disposal/recycling. This means that during the packaging development process, the label must be regarded as an integral part of the product/pack mix and be fully tested to ensure that it conforms to all requirements.

The current (2009) *FINAT Technical Handbook* outlines 27 test methods which can be used to test many aspects of self-adhesive label materials for specification and production. Although these are not ‘official’ standards, they are widely used by suppliers and printers throughout the world. They are perceived as a universal standard for determining certain characteristics. This publication, together with the

FINAT Educational Handbook, provide a very useful source of information on label production for the student.

17.10 What can go wrong?

It is important to get the production of the label right first time as the further down the production chain a problem arises, the more expensive it is to put right and the longer it takes to produce. The opportunity cost of re-printing can be very expensive. Apart from technical problems during the printing and finishing stages, there are many areas where disputes can occur between the parties involved in the production process. It is essential that proofs are signed off at each stage of the production process; in this way everyone knows what is expected of them and corrections or modifications can be made early in the process.

Starting well before printing and pre-press artwork is produced, it is imperative that the specification of the label is accurate and accepted, and is understood and signed off by all parties. This will include the brand owner, the designer, the printer and the filling company. This stage is essential and time should be taken to ensure that everyone in the supply chain understands what is expected at each stage in production. This is the time when the specification of the substrate and adhesive is agreed. This is also when the end use of the label is specified, the type of container, the printing process, the method of filling, and the expected life of the label on the product, to name just a few criteria.

One of the most important factors for the brand owner is colour consistency not only from pack to pack but from batch to batch over a prolonged period of production. Meeting the colour specification is probably one of the greatest areas of contention between brand owner and printer, which is why exact colours must be specified if possible using a 'standard' colour system such as Pantone as a reference.

Another problem area is the actual printing. Although the label is a transitory element in the life cycle of a product, it must be presented to the highest quality commensurate with the type of end product it is to be used on. The biggest single fault is mis-register between one colour and the next. This of course has to be within accepted tolerances. For example, this may not matter on a tin of peas, but if this occurs on a pharmaceutical label, this could prevent the information from being easily read. This also applies to 'heavy' printing where overimpression or overinking can make some typefaces (especially 4pt and below) illegible.

The golden rule is to specify and obtain agreement at the earliest stage in the label production chain.

17.11 The label market

What is the current status of the label market and what are the trends for the future. What is affecting the growth of the label industry?

There is increasing globalisation of suppliers to the industry and their customers, and major brand owners are also becoming more global. This means that these brand owners are looking for global converters/printers who can supply labels in the locality of the product manufacture. There are relatively few global printers which indicates that there are potential business opportunities available.

Self-adhesive labels dominate the label converting sector which is also increasingly producing other types of labels. Sleeves are seen as a potential expansion area as are wraparound film labels. As mentioned elsewhere, wet glue applied labels are steadily losing market share even though their market volume is increasing. In-mould labels are still perceived as a relatively small niche market. The boundary between flexible packaging and label converting is becoming less distinct.

During the past few years flexography has become the dominant process worldwide with UV flexo growing rapidly. In addition digital printing has become a mainstream process in most developed markets. Letterpress continues to decline in volume yet offset litho is enjoying a revival. Foiling is becoming more popular due to the introduction of cold foil techniques.

17.12 The digital revolution

Almost every aspect of label production has a digital input at some stage: design and artwork, scanning and cameras, proofing and page make-up, plate-making, printing, finishing, quality inspection and die cutting. More than 12% of new label presses are digital or have a digital unit. Stand alone digital presses are being introduced which operate at commercially acceptable speeds to make them viable alternatives to conventional printing techniques. The ultimate would be control of all the operations digitally through management information systems (MIS).

17.13 Conclusion and future trends

The use of digital printing of labels and tags will become more widespread. RFID and other smart technologies will grow rapidly. The use of label printing technology will become widely used in the new and evolving 'printing for electronics' market; this is seen as an additional segment not as a replacement technology. Anti-counterfeit and product authentication applications are growing to respond to the enormous current counterfeiting activities. There are major new advances in nano-materials which will influence the way labels are employed on high value and pharmaceutical products along with developments in anti-microbial and anti-bacterial label products. Techniques are in the development stage to use labels to detect MRSA, E-coli, BSE, Asian bird flu and many other viruses. There will be nano sensors to track food from the farm to the plate. As these techniques are introduced so the importance of security inks and materials will become more important. Smart, active and intelligent labels will offer new opportunities.

The opportunities for the label industry in the future are enormous and will see the label industry grow and diversify considerably over the next 5–10 years.

17.14 Sources of further information and advice

Fairley M., *European Label Survey 2007*, Tarsus Group, London.

Fairley M, *Label Market Trends 2008*, Tarsus Group, London.

Fairley M, *World and European Trends 2009*, Tarsus Group, London.

Labels and Labelling International magazine (monthly). Visit www.labelsandlabelling.com

NarroWebTech magazine (quarterly). Visit www.flexo.de

Spring, R. (ed.) (1996) *FINAT Educational Handbook: Self Adhesive Labelling.* FINAT, The Hague. See also: *FINAT Technical Handbook (Test Methods) 2009.* FINAT, The Hague.

18
Packaging design and development

B. STEWART, Sheffield Hallam University, UK

Abstract: This chapter firstly considers the packaging design process, describing the interaction of elements and activities that make up a typical design study. It then examines each of these in greater detail, beginning with the brief and progressing through research of both technical and market issues. Description of the design phase follows, looking at stimulating creativity, generating concepts, working with both structural and graphic elements through to analysing design candidates and recommending solutions. Finally, the process is illustrated through a case study.

Key words: packaging, design, graphic, standout, branding, brief, lifestyle.

18.1 Introduction

The fundamental needs for packaging are echoed throughout this book but we can be sure that packaging must be effective in containing, protecting, identifying and promoting products and it should do so with the least impact on the environment and at minimum cost. Clearly, we have here a mixture of technical, environmental, financial and communication issues to resolve even at the most basic levels of packaging design. Frequently the emphasis on each of these issues varies. Few of us are likely to question the level of packaging required to ensure, for example, that hospital supplies, swabs, needles and other medical items are sterile and unambiguously identified for the benefit of the medical team using them and, ultimately, for us, the patients, wherever in the world we are being treated. Here, the emphasis is to deliver packaged products that guarantee unwavering performance at minimum cost. Considerations of environmental impact and branding, while not ignored, are of less importance. In fact, even here, good packaging design can provide benefits for medical staff by, for example, being easy to open and use under medical conditions.

By contrast, the packaging of fast moving consumer goods, particularly within self-service retail environments, is a direct consumer interaction. It demands that the function of identification be greatly augmented to include promoting the brand and, importantly, allowing the packaged product to stand out from competitors' products. The pack in this scenario is often the only channel of communication between potential purchaser and product and, while pack cost and environmental performance are still vital components, sales performance dominates.

When we move to luxury goods, the relationship between functions becomes even more distorted. Here, in the case of packaging for fragrances, for example, the pack cost may exceed the product cost. We are buying the image, the dream, the brand and the envy of others. Packaging in this scenario becomes primarily the purveyor of status with cost and environmental considerations relegated to the background.

Less dramatically perhaps, creating packaging that reinforces the emotive bond between product and user is often a key component of a brief across a range of products. Costs and environmental performance are still key issues in all design studies.

In this chapter, we shall consider how the design process works, how it incorporates these issues and the parts played by each of the component parts of the process itself. Using a case study, we shall gain a practical insight into how packaging designers tackle the task, how creativity might be stimulated and what tools they might use to help express their ideas.

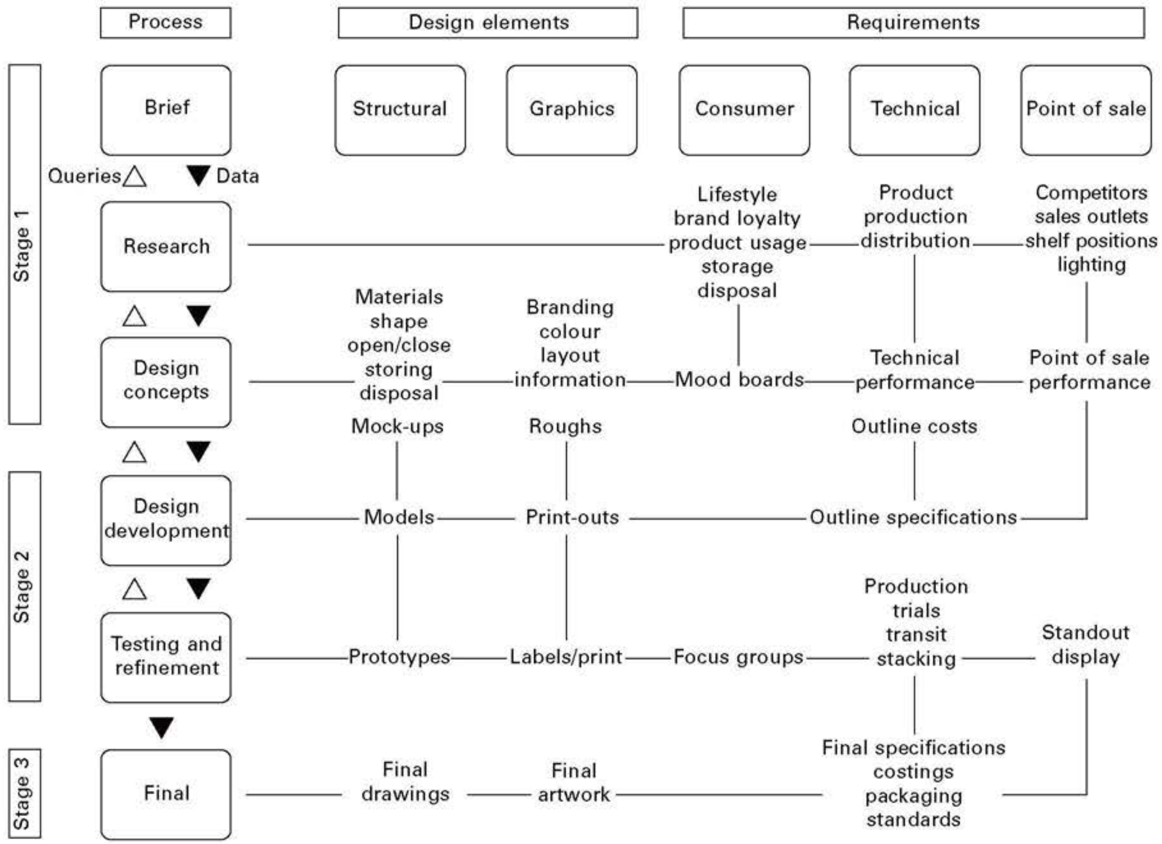
18.1.1 The design process

Figure 18.1 shows the design process represented by a logical progression of events, beginning with a brief, followed by a research phase, conceptual designs, through to developing design candidates worthy of progression, testing, refinement and final recommendations. The chart also indicates how the elements of structural and graphic design fit within the process and how the requirements of consumers, technical aspects and sales are fed into the study. While all these functions need to be considered even for the most modest packaging project, it should be understood that the linear nature of such charts tends to conceal a cyclical process also taking place within the process itself where different design concepts are being originated, developed and assessed. Frequently designs will be tried, refined, tried again and so on, ultimately being progressed as potential design solutions or rejected along the way.

There is seldom just one solution to any design problem. It is more likely that a number of design solutions emerge, some perhaps more costly but offering consumer benefits, others perhaps providing better distribution efficiencies or improved environmental performance. In many instances, the overall design is likely to be a compromise but one that must have a strong rationale for supporting it.

Figure 18.1 purposely simplifies the design process for clarity. Most packaging design companies break down a study into a series of stages. Figure 18.1 shows a typical three-stage packaging project where stage 1 involves research and concept creation. This is usually the most important and longest stage where creativity is being challenged. At the end of this stage, it would be usual to present conceptual work to a client, together with recommendations for further development of preferred design candidates. The project then progresses to a second stage where concept development and product/pack testing and evaluations take place, ending as before with a client presentation. Finally, in stage three, with specifications, drawings and artwork completed, the project ends.

This represents a typical packaging design project but a major project can extend over many months, involving multiple suppliers within different countries using different machinery. Consumer testing, again often in different countries, can yield results requiring slight modifications or even a radical design rethink. We can now consider the component parts of the design process in greater detail.



18.1 Packaging design process chart.

18.1.2 The brief

The project brief is probably the most critical part of the design process. It not only begins the process but becomes a reference throughout the lifespan of the project and, ultimately, is the yardstick by which success or failure will be measured. It is not something to be read before design work begins and then discarded. It accompanies work at every stage so that the design team can question whether or not their concepts meet the brief. No matter how clever or ingenious we might consider our individual design ideas to be, if they do not meet the brief we are simply wasting time.

It is true that briefs can vary and some packaging designers might claim that they worked from a brief written on the back of a paper serviette. The majority, however, will be more familiar with receiving a verbal briefing by the client accompanied by a comprehensive written briefing document. Most of the larger corporations and major brands work in this way, where the brief is provided by marketing staff or brand managers, often to consultancies on their 'roster' of design companies. As might be expected, frequently briefs from these sources are comprehensive, citing brand values, amongst many other attributes, that must be incorporated into the design work. The brief might be accompanied by market research results, competitor analysis, an advertising strategy or other data that helps the design team really understand the exact task ahead.

Smaller companies may not have the resources to employ such specialists and may encourage some assistance from designers to help establish a valid brief. For designers, this too can be rewarding as packaging designs at this level may be of greater significance in shaping company strategy. The design team members have the opportunity of demonstrating their expertise in design but might also augment that by contributing their experience of market sectors, human interaction or of other areas useful to the project and the client company.

The structure and organisation of client companies clearly show wide variations. Some employ their own in-house packaging specialists and design team, where technical packaging experts, purchasing managers, graphic and structural designers respond to marketing strategies. In this scenario, familiarity with product, production, suppliers and distribution capabilities provide a clear advantage over bringing in outside designers. A disadvantage sometimes results from such familiarity however, by a reluctance to challenge established company conventions or disturb departmental budgets. Understandably, a production manager, for example, may not welcome a design proposal that requires installation of new, unfamiliar plant and machinery that uses up his entire budget. Conversely, other production managers may be delighted at the prospect and have been pro-active in pressing for it. Many companies also respond to supplier led innovations, where packaging suppliers and client company work together developing new concepts.

Clearly there are many routes to packaging design that may involve designers working alongside specialists from marketing, production, advertising, distribution, suppliers, merchandising, sales, legal and environmental/sustainability departments, and, of course, packaging technologists. In this chapter, in order to highlight the packaging design process itself, we have elected to consider design as a separate entity. So, while reference is made to design consultancies, the design process remains broadly the same for in-house design teams and other organisational arrangements.

As with client companies, the structure of design companies also varies in size, structure, speciality and track record. On one hand, there are small studios with just two or three designers; on the other, major companies with offices throughout the world. Somewhere in between lie many well-established consultancies employing 20 or 30 staff.

Whatever the nature of both client-company and designer, design projects begin with a brief. Typically, a packaging brief will contain the information summarised in Table 18.1. While the emphasis is likely to vary from project to project, all the information categories listed here should, at least, be considered on all packaging design studies.

Many design consultancies view the brief as being of such significance that they take the time to review it with their team and feedback their understanding of the brief to the client. In this way both parties can be sure that all details are confirmed and no misunderstandings are likely to surface as the project progresses. This is also the point that a design consultancy will normally respond to a potential client with an indication of fee costs and timings, often broken down into stages.

18.2 Research

While the brief establishes the aims and parameters of the design project, further research is inevitably required before any design work begins. This may be, for example, to help the designer or design team fully understand a market that is

Table 18.1 Checklist for a packaging brief

Market information	
Product	Sizes/weights/volumes – purchase motivation – brand loyalty – brand values
Market	Size – value – trends – brands, brand share – seasonality
Target audience	Age – gender – lifestyle – purchaser/end-user – decision maker
Consumer benefits	Carrying – opening/closing – dispensing – storing – after use – disposal
Competitors	Brands – products – categories – cannibalism
Technical information	
Product protection	Moisture – light – temperature – gases – mechanical damage
Product compatibility	Materials – shelf life – deterioration
Production	Filling – closing/sealing – printing/labelling – secondary pack
Distribution	Warehousing – transport – tagging/tracking
Merchandising/pos	Outlets – fixture types/sizes – shelf position – lighting
Environmental and legal information	
Material sources	Renewable resource – recycled – sustainability – energy – impact
Pack construction	Monomaterials – separation of components – weights/bulk – energy
Disposal	Reuse – recyclable – compostable – toxicity
Marking	Symbols – weights and measures – copy sizes – hazards

unfamiliar to them or, perhaps, see for themselves what point-of-sale conditions are like. There are a number of research areas designers need to consider at the outset of a design project, some of which may be very specific to the nature of the product or area. While, for example, the packaging of medical products for hospital use may place a different emphasis on the direction of research, nevertheless, all the research shown in the following sections should at least be considered in all packaging studies. Broadly, research can be considered in two sections: marketing considerations and technical considerations.

18.2.1 Researching marketing considerations

Referring to Table 18.1, we can see that, even before any design work can begin, there is a substantial amount of background information to be gathered. Without an understanding of the market and a knowledge about the consumer/purchaser/end-user, designs would be created in a vacuum and lack any clear focus. The main areas for further investigation are outlined below.

Product positioning

Client marketing groups will often spend time explaining how they anticipate the product being positioned in the market. We can consider an example to illustrate how this can be done. A confectionery manufacturer briefing the design team explained how the product, a chocolate truffle bar, was to be positioned as an 'indulgent treat'. They had identified the market as being almost exclusively women who wished to reward themselves with a small treat for accomplishing a task. The rationale was that, having taken the children to school, completed the ironing or taking a break in the office, a little time could be set aside for a treat and the indulgence justified in terms of calories expended finishing the task. We also see this approach in advertising, the *'just because you're worth it'* campaign by L'Oreal, for example or, more directly, Nestlé's Kit Kat, *'have a break, have a Kit Kat'*. It is important for designers to investigate the purchasing motivation of the purchaser or consumer as it will have a direct outcome on the design work. In the above example, rich dark reds and golds were used to underpin the positioning of the product in the indulgence market sector.

In some instances products may be bought as 'distress purchases'. These are items that are usually bought quickly, reacting to a domestic crisis or forgotten birthday for example. Product category identification and branding are particularly important here as purchasing decisions are being made almost instantly. A 500 ml bottle of mineral water with a distinctive shape associated with an established brand is likely to be selected as a safe bet, preferable in circumstances of limited time, to examining the alternatives before making a decision. If visual standout against competitors is critical in such circumstances, it is also important in almost every other situation. Even when purchasing behaviour is more considered and less pressured by time, rapid brand and product identification is one of the most important attributes of packaging.

Brand values

Brands are often a company's most valuable asset, often representing, in monetary terms, many times more than the value of company land, plant and machinery combined. Company take-overs are frequently about the acquisition of brands rather than just physical company assets. A successful brand, therefore, has a monetary value based on its ability to sell products, together with an emotional appeal to its target market, carefully nurtured by marketing and advertising strategies usually over a considerable period of time (Table 18.2).

If the project concerns packaging a branded product, it is vital that the values of the brand are accurately reflected, reinforced and promoted by the packaging design. To achieve this requires that the designers understand and become familiar with the brand's values. We, as consumers, might assume that we buy a particular brand because our experience of it has been positive, for example a cleaning product that we have found to be effective in the kitchen or a savoury sauce that we really like. Both are examples of products that physically satisfy our needs. In addition to this, however, we form emotional bonds with such brands, often based on trust. Probably all baked beans are much the same but we might select Heinz, for example, because it is our 'old friend', the one we trust not to let us down. The Heinz brand has changed little in over 100 years and it is of little surprise, therefore, to find that the packaging of Heinz baked beans is distinctive, standing out from the competition and making in-store selection an easy task. For many, choosing 'our' brand for the price of a small premium makes product selection quick, easy and risk free.

As with 'trust', most brand values are expressed in human terms, reflecting their emotional value. Descriptors like 'serious' or 'fun' are often used. Brand values associated with Apple, for example, or Apple's brand personality to put it another way, could include 'imaginative', 'rebellious', 'passionate' and 'different'. An iPhone or iPad becomes an object of desire rather than simply functional electronics. Apple has been successful in promoting its brand values and creating a loyal following of consumers eager to purchase and, importantly, to be seen by others, to purchase Apple products. Whatever brand the packaging designer might be working with, it is vital that brand values become intertwined with all stages of the design process.

The market

Packaging designers need to gain an insight into the market that the project is addressing in order to respond to its demands. In particular, they need to get a feel of how the market is developing, what trends are driving it, which brands are succeeding and why this is the case and which brands are losing market share. It may be important to the study if there are seasonal factors that affect the market and, if so, how these can be incorporated within the design task. Later in this chapter the case study reveals how market information drives the direction of design work.

Table 18.2 Top-branded products

2009 rank	Brand	Country of origin
1	Coca-Cola	US
2	IBM	US
3	Microsoft	US
4	General Electric	US
5	Nokia	Finland
6	McDonalds	US
7	Google	US
8	Toyota	Japan
9	Intel	US
10	Disney	US
11	Hewlett Packard	US
12	Mercedes Benz	Germany
13	Gillette	US
14	Cisco	US
15	BMW	Germany
16	Louis Vutton	France
17	Malboro	US
18	Honda	Japan
19	Samsung	Korea
20	Apple	US
21	H&M	Sweden
22	American Express	US
23	Pepsi	US
24	Oracle	US
25	Nescafe	Switzerland
26	Nike	US
27	SAP	Germany
28	IKEA	Sweden
29	Sony	Japan
30	Budweiser	US
31	UPS	US
32	HSBC	UK
33	Cannon	Japan
34	Kelloggs	US
35	Dell	US
36	Citi	US
37	JP Morgan	US
38	Goldman Sachs	US
39	Nintendo	Japan
40	Thomson Reuters	Canada
41	Gucci	Italy
42	Phillips	Netherlands
43	Amazon	US
44	L'Oreal	France
45	Accenture	US
46	ebay	US
47	Siemens	Germany
48	Heinz	US
49	Ford	US
50	Zara	Spain

Source: interbrand, Best Global Brands, 2009

Target audience

All packaging design work needs to provide a communication between the product, brand and the target audience. In many situations including all self-service transactions involving packaged goods, the pack plays a critical role in communication. In most situations the purchaser may also be the consumer but often, say in the case of a mother shopping for her family, the purchaser may be buying for someone else. If mum is accompanied by family members, she may be influenced in her choice by them. We must establish, not only who the principle targets are that we are designing for but begin to understand their motivations. The target audience will often have been identified by the client in the brief but now, at the start of a project, our task is to identify and understand what motivates them, identifying their wants, needs and desires. This can be done in a number of ways.

Demographic data provides statistical and numeric information about populations that can provide a useful input to a design study. It is helpful to know, for example, in a study concerning speciality teas, that the fastest growing market sector is amongst the 25–35 year olds, although the majority of tea drinkers are currently in the 55+ age group. Failure to understand such details can drive design work in the wrong direction, in this case aiming at an older market when, in fact, younger consumers are more promising targets.

Psychographic data, by contrast, is concerned with people's beliefs, opinions and lifestyles and seeks to identify the motivations of groups of like-minded people. Often these groups are given names, reflecting their shared lifestyles. For example, we might describe 'urban adventurers' as city dwellers, driving black 4×4s, brand aware, 'cool', health club members, living in a flat within a gated development, chrome and glass décor, skiing in France, enjoying dining out or elaborate meals at home with friends, and so on. Descriptors like this are immediate and vivid, helping designers understand the target audience and providing clues about what might motivate them and drive their purchasing decisions.

Both the above types of data can be sourced from published reports and surveys. There are many lifestyle magazines that reveal, through their articles and the type of advertising they include, details about particular groups of people. Additionally, field research conducted by designers themselves can supplement this information and contribute towards creating a market profile. This might involve direct observation of a target group's behaviour, organising focus groups to discuss lifestyle choices, brand selection and motivations for purchase or, as we will see in the case study, simply talking to friends and family if they happen to be in the target group concerned.

By following these research techniques, a consumer profile begins to emerge. It can be further developed by probing deeper into the lifestyles of the target group. We may, for example, want to question which brands they might buy, what car they might drive, where they are likely to go on holiday, their choice of music, and so on. Designers often try to encapsulate this information by creating mood boards. A mood board is simply a collection of images, tear sheets from magazines, sketches, materials, colours or any other items that represent the target market's lifestyle. It helps encapsulate target market research into a visual reference, meaningful to designers or a design team. By considering the target audience in this level of detail, it becomes easier to design products and packaging that will appeal directly to them, creating an emotive response that is likely to encourage and maintain product and brand loyalty.

Consumer requirements and benefits

How packs perform from purchase, through storage, in-use and disposal is an important consideration for consumers and, therefore, important also for designers. Some products might benefit by allowing inspection prior to sale. Abrasive papers in the DIY market are an example here. Consumers might also expect packs to comply with any market sector protocols and be confused if they do not. A green coloured chicken stock cube breaks the 'yellow for chicken' that has become an established convention.

Good packaging design can recognise consumer needs and build in consumer benefits through an understanding of these areas; for example, simplifying the opening and re-closing of containers, the ease of dispensing or pouring product and providing containers that are stable in the environment where they are used (Fig. 18.2). A shower gel that can be dispensed one-handed and does not topple over when placed on a shelf would clearly provide a consumer benefit compared to other brands that might have adopted a pack format that has not considered end use.

For some specific target groups, building in these types of features should be part of the brief. With an increasing market of people aged over 60, for example, it is becoming more important to consider issues of manual dexterity, when joints become stiff and painful and where the ability to grip is weakened. The over 60s, however, are not one coherent market. The category fragments into sectors from fit and healthy through elderly and infirm to those in care. Any packaging design that aids opening a tin, for example, must be inclusive, suitable for all ages and not stigmatise one sector. Currently, research is ongoing to make ring-pull tops easier to use. The study, taking place at Sheffield Hallam University, has identified that many people struggle to lift the ring-pull into a position where leverage can be exerted. One simple solution, amongst several being trialled, is to incorporate a recess under the ring making the operation much easier – for all, not just the elderly. Clearly, where brands and products are perceived as being designed with end-users in mind, in terms of ease of use, storage and disposal, they are likely to encourage repeat purchase and brand loyalty.

Competitor products

Products, brands and packs compete against each other on-shelf. Clearly, for designers, it is important to recognise the strengths and weaknesses of competitors, particularly within a supermarket environment, where the retailers follow their own merchandising strategy, largely outside of the control of brands. This becomes increasingly important where brands introduce product variants. Five different flavours of crisps from the same brand can begin to compete for market share with each other without actually

18.2 Using packaging to benefit the consumer. Consumers require a pack that is stable and easy to use within its environment. Here, the pack is designed to be always on display, reinforcing the brand at every use.

increasing overall sales. This is referred to as cannibalism, where, for example, smokey bacon flavoured crisps might erode the sales of cheddar cheese flavoured crisps, while, overall, total crisp sales remain static. Designers should also be aware that the product or brand they are working on may compete against a different category of product adjacent to it in the aisles. Loose tea and tea bags often, in this way, compete with roast and ground coffees. Category, product and brand standout are even more important in circumstances such as that. Standout is probably the most significant challenge for packaging designers within retail markets.

18.2.2 Researching technical considerations

To ensure that all information is in place, the checklist (Table 18.1) provides a detailed list of considerations. Not all apply to every design study but, by checking them all, you may be assured that nothing has been overlooked. The sections below indicate some of the principal areas that designers have to address.

Containment, protection, preservation and compatibility

As covered in Chapter 2, the technical functions of packaging are fundamentally concerned with containing, protecting and preserving products. Containment seems obvious, but in many instances the pack design must be effective in not permitting any unwanted product loss during the total product lifecycle, including such times when the product is partially used and then stored. Packs must protect their contents against degradation or spoilage, most frequently caused by moisture, oxidation, UV light, microbiological contamination, temperature extremes and odours. Additionally, any known compatibility problems between product and packaging material should be recognised as, clearly, this will impact on the choice of packaging materials, often eliminating some at the outset. There are often shelf life requirements that will also eliminate some packaging materials from subsequent design considerations. Although, ultimately, packaging design culminates in producing packaging specifications, in the early stages of a study, a broader approach is acceptable. If, for example, we know that flexible laminate films work for similar products, we do not need to discuss detailed specifications until later in the study.

Production, distribution and point-of-sale

In the research phase, before design begins, designers should, wherever possible, gain an insight into how products are produced, packed, distributed and sold. Seeing how jam is made, for example, how jars are filled, sealed, labelled, collated and packed into secondary cartons, provides a useful backdrop to any packaging design study. Designers begin to get a feel about the nature of the product at different stages and the speed of production lines. They can see, at first hand, the importance of retaining contact points on jars, for example, helping to eliminate conceptual work on new shapes that will not provide sufficient pack stability on the lines.

Similar practical details will be revealed when warehousing, handling and transport operations are visited. For packaged products, particularly those produced in large volumes, packaging design impacts directly on the 'bottom line'. Efficiencies gained in palletisation, warehousing, transport utilisation and weight reduction, all contribute to profitability. Packaging design proposals that challenge any of these areas have to be justified, usually through their potential to increase sales.

There are also efficiencies at point-of-sale where pack size and configuration may influence both technical and graphic design. Technically, shelf optimisation is frequently an issue. Graphically, the main sales panel of the pack should present itself to potential purchasers. It is unrealistic to think that retail staff will have time to spend rearranging packs. In addition, by seeing the point-of-sale conditions, the designers can see what actual conditions are like. Ice cream tubs, for example, might be displayed in a chest type freezer where the lid is the most important panel and where the job of product description and branding needs to be strongest.

By experiencing the above areas through visits, a valuable body of knowledge is created concerning the practical implication of design decisions. There is a danger, however, that feeding this information too early into a study might restrict creativity in the subsequent design work, stifling imagination in favour of practicality. Feed it too late, however, and time might be lost working on concepts that have no practical application. Most design teams deal with this dilemma by having a technical specialist who will allow some creative work to get underway and guide the direction it is taking. For individual designers, the task may be harder, working creatively and then analysing results. Fortunately, we are built with brains that allow us to be creative on one side and analytical on the other. Packaging design challenges both.

Environmental considerations

Although it is convenient to separate out a section on environmental considerations, in practice all design work should be underpinned by environmental considerations at all stages of the design process. We should begin by questioning whether the product needs packaging at all. In some instances, it might not. Certainly, there are instances where point-of-sale (POS) units could remove the need for retail packaging. DIY hardware, drills, sanding discs, etc., are robust enough to survive without packaging. They can be identified by POS material and protected against theft by microchip. If packaging has to be used, then it should be at minimum levels. The packaging industry has quietly but effectively worked in the background, reducing packaging levels, for example, by lightweighting containers. Even so, designers should seek to minimise the impact of packaging by removing it where possible and minimising packaging levels where necessary. By using mono-materials, or, at the very least, enabling different materials to be easily separated, recycling and composting by consumers is eased. In many instances, recycled materials can be used to create new packaging. For some products, a closed loop system of packaging might be a solution, where containers are returned to a central location for refilling.

Although designers should always strive to minimise the impact of packaging on the environment, it should be remembered that the often high value of a product is being protected by the relatively low cost of packaging. In other words, the energy invested in the product is protected by a very much lower level of energy invested in the pack. Should the product become damaged, not only is there an energy loss but additional energy wasted in obtaining a replacement. Additionally, food packaging, in particular, helps to extend product shelf life, reduce product spoilage and increase consumer choice. These are difficult factors to resolve within the complex situation of balancing feeding the world's population while also preserving the planet.

18.3 Conceptual design

With a thorough knowledge of the product, market, consumer profile, production, distribution and point of sale conditions, design work can begin. Of course, while all the above activities have been taking place, some ideas will already have been forming. What we need now is a free ranging supply of ideas, even those that we might discard later. This stage of packaging design is the creative phase where thinking should be lateral as well as logical. It is the most critical part of any design study and often the most extensive in terms of time and cost.

18.3.1 Sources of inspiration

Many inexperienced designers put off starting design work by prolonging the research phase, collating more and more material. Now, faced with a blank pad of paper and empty screen, it can be difficult to get going. In commercial practice, designers often work in teams. This has the benefit of combining the differing skills of individuals but is also valuable in that ideas can emerge during discussion and debate within the group. It is also useful to create a stimulating environment based around the project by bringing in samples of the product, competitor products, mood boards and other materials that relate to the product or brand.

When working on the packaging design for a natural range of products, one highly acclaimed design company created a 'natural' environment within the studio, including an astro-turf floor. This might be going too far but for such a brief involving natural products, why not get the design team into a field, farm or botanical garden? Another agency gave a sum of money to each member of the design team and gave them a time limit of one hour to go out and buy packaged products that they most admired. If the project involves, for example, snacking on-the-go, get the team or individual designer to watch what people actually do in stations, parks, around offices and, if possible, take photographs. The point here is that creativity is stimulated by external factors so that it is worth replacing the situation of blank paper in a sterile office by something a little livelier.

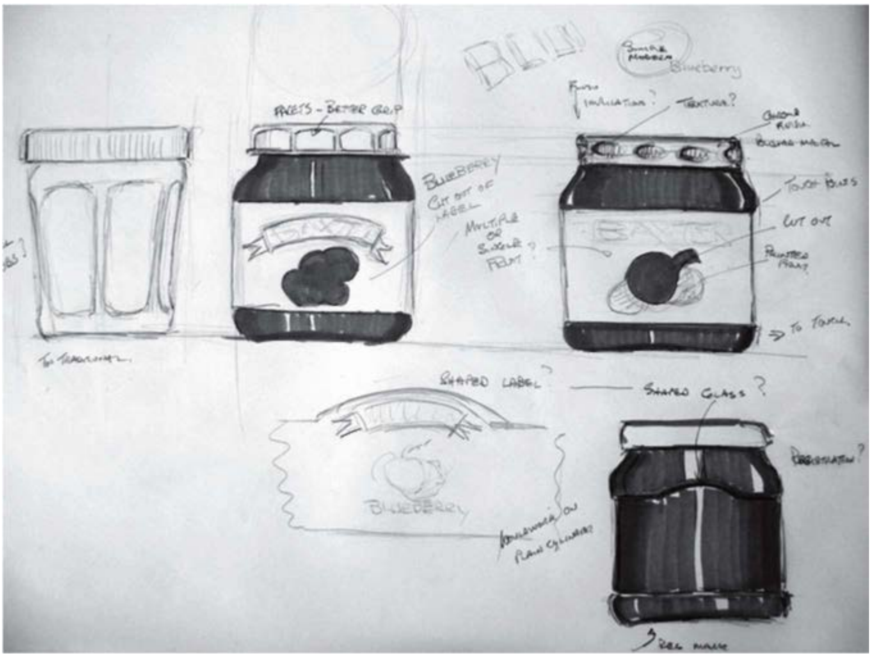
Another frequently used technique is brainstorming. Here, a group of designers is encouraged to suggest concepts, even implausible ones with all ideas being noted for subsequent discussion. It can be surprising how some, initially crazy, ideas can be modified and adapted to provide interesting design solutions. To get the best out of brainstorming, sessions should be properly structured and there are sources of information recommended at the end of this chapter.

18.3.2 Generating concepts

The process for creating conceptual designs will vary depending upon the nature of the project but where both structural and graphic design is required, where do we begin? In this section we show that while the two elements cannot be considered entirely separately, the usual progression of events looks at structural design first.

Ways of working

It is perhaps worthwhile at this point considering some of the ways that packaging designers work. Many work directly with sketches for both structural and graphic concepts, quickly generating ideas and exploring both technical and graphical features as they go (Fig. 18.3). Others, particularly on a structural project, prefer to create three-dimensional rough mock-ups, using simple materials such as paper, board, solid foam, clay, plasticene, wood or by modifying found objects. Whatever medium is used, it needs to allow concepts to be generated quickly without hindering creativity. Precision is not required, just a standard capable of communicating a concept. Computer generated work is far too slow and limiting in this initial stage.



18.3 Sketch of glass jar project showing how the structural design is complemented by working on the label design at the same time. Here cut-out parts of the label reveal the colour of the jam.

If the project is concerned with both structural and graphic design work, each structural concept needs to be accompanied by a rough indication about how the pack form could be decorated. (Decoration is the term used to include all forms of graphics and includes direct print, labels, sleeves, embossing and debossing.) In this way, we might, for example, consider the shape of a new household detergent bottle while simultaneously evaluating how it might be decorated. In practice, however, where structural design is required as part of a packaging design study, it is usual to begin by considering this first, realising that it should not prevent evaluation of the graphic potential of structural design candidates.

Structural design

Structural packaging design concerns working with shape and materials. Any one category of materials imposes design constraints through the nature of the material and its ability to be converted into packaging. It would be usual, therefore, to begin a study by considering packaging options broadly, in terms of packaging types. Could the product be packed into rigid tubes, jars, bottles, cartons, flexible tubes and pouches, thermoformed trays, tins, tubs, sleeves, etc.? Sometimes, importing a pack form from another area provides a distinctive ‘new’ design, as in the example shown in Fig. 18.4. Here a board container associated with liquids now provides a convenient and easy-to-use dispenser pack for sugar.

18.4 This French pack for sugar demonstrates how a pack from one market sector can emerge as a new and interesting design in a totally different sector. It is also very easy to use and store.

Technology is also providing new materials and creating new opportunities. Working at sub-molecular levels, nanotechnology has already provided self-cleaning surfaces, plastics with the strength of steel and transparent waterproof paper. Electronic technology has established radio frequency identification (RFID) systems that we are all familiar with, particularly in the form of security tags. They are, unsurprisingly, becoming increasingly sophisticated, smaller and capable of storing data and programmes. Already they are used on-pack to monitor transit conditions and product deterioration. When this technology is combined with miniature paper batteries and electroluminescent inks, packs can provide information, display animated graphics and interact with other devices. Microwave packs that self-set the timer, packs that send text instructions to your mobile phone or update your computer shopping list when they are empty – all are possible now. When selecting materials, designers need to be aware of these new and fast developing ranges of possibilities.

At this point, probably designers will be working with sketches as a fast and efficient way of exploring initial ideas. It is a good idea, however, to quickly move to sketching packs at their approximately correct sizes. Working at 1:1 scale often reveals practical issues that can be masked by smaller sketches. Mock-ups are a great way to bring pack concepts to life. They need not be elaborate but good enough to provide a visual reference to the pack form they represent. Here we also need to be able to understand what materials are being represented by mock-ups and sketches and how they might be decorated.

Graphic design

Conceptual graphic design work may be running in parallel with structural design or following it or, more usually, a bit of both. Until the structural design is established and the materials decided, graphic design can only remain conceptual. Nevertheless, it can suggest directions from an early stage. It might explore photography versus illustration, branding and sub-branding, colour, use of imagery, investigate typography, or consider corporate requirements.

Importantly, any graphic design must be effective on the panel most seen by consumers at point-of-sale. Deciding which panel will become the main panel is normally a first step. It is not always the largest panel. Earlier research should indicate how the product/pack will be displayed. Sometimes it might be the end panel of a carton that is seen and, if so, this is where graphic design will be most critical. Having selected the main panel, the field of vision needs to be checked. A cylindrical container offers a restricted width for graphic visibility, for example, often reducing the available area to carry branding and product descriptor. It is better to establish such restrictions early in a design study to avoid spending time developing graphics that do not work when applied to the pack.

Analysis

It would be usual for the design team to hold an interim meeting at this point, putting all their individual ideas on the table and discussing the relative merits of each, relegating some design candidates while promoting others for further development. The brief is always used as a reference for judging the success of any design candidate. In some instances, designs might be found not to meet the brief but most often design concepts will meet some aspects of the brief. It becomes a question of degree. There are also the practical aspects of production and implications for transport, distribution, warehousing and point of sale to be considered, together with costs. These now also begin to become criteria for judging designs.

It is rare for one individual design to succeed at this stage. Design A might provide terrific standout but present filling problems, while design B provides efficiencies in storage and transport but lacks shelf impact and differentiation from the competition. Some design groups use assessment grids to rank design candidates; others do so more informally. Table 18.3 shows some assessment criteria that might be used to rank design candidates. All, however, must now decide which designs need further development and, almost certainly, there will be more than one.

Often, too, some concepts might be identified as benefiting from cross-fertilisation,

Table 18.3 Assessment chart for design concepts

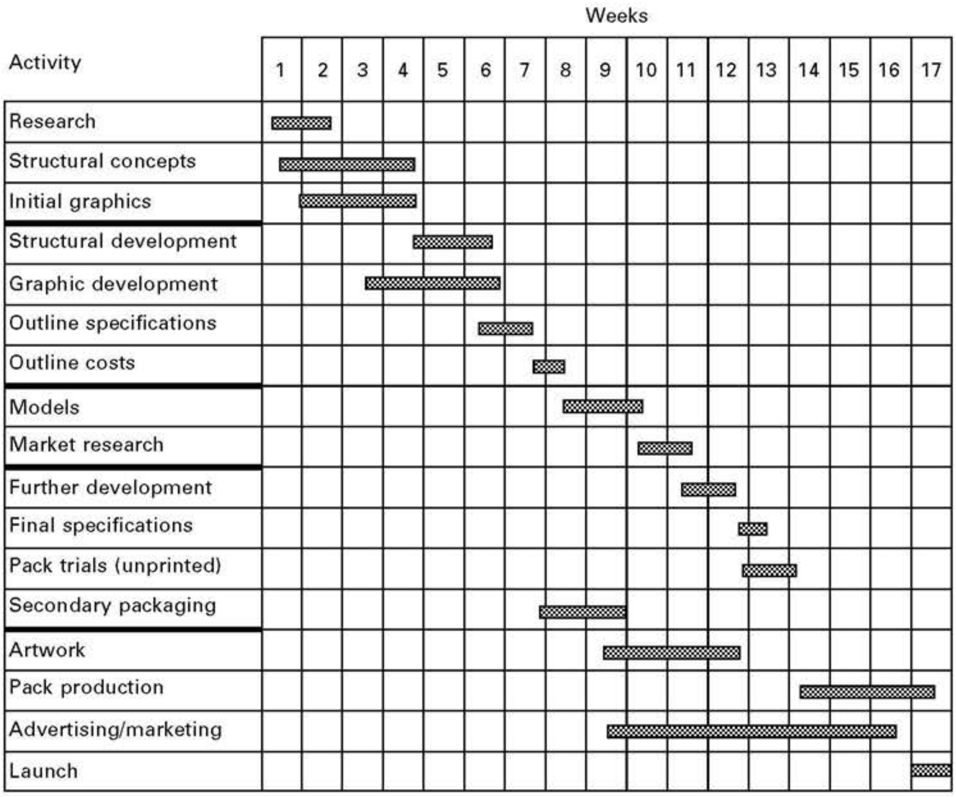
Standout – which design provides greatest standout				
against other design candidates		against competitor products within the same product sector		against surrounding products in adjacent sectors
Imagery and tone – which design provides				
right 'voice' (serious, fun, healthy, etc.)			resonance with target audience	
Branding – which design				
promotes the brand		represents brand values		
Believability – which design is most believable				
Fits with product sector		Looks the part		
Graphic layout – which design candidate follows design 'rules' in terms of				
typography	legibility	balance	colour	images
Aesthetics – which design looks the most				
elegant	integrated	exciting	effective	
Practical and technical issues – which designs are				
cost effective	transferable	allow promotions	not recessive at POS	
meet legal needs	environmental	production friendly	transport efficient	

combining positive points between designs and creating hybrid design variants. In a commercial packaging design project, at this point the work conducted up until now, the first project stage, would be presented to the client. All work would be shown, recommendations made and a rationale provided for developing favoured designs.

Design development

In many packaging design studies, the development process might extend into many months. On the marketing side, there may, for example, be consumer testing to take place. Technically, there may be filling trials, transit trials and other tests that need to be conducted before any new pack form can be introduced. In order to ensure that all activities are coordinated, it is usual to produce a chart indicating activity, timing and staff resources required. Once agreed by all parties, this document schedules all further stages in the development process through to product launch, imposing deadlines for completion of all interim activities. There are many software programs that can create project charts and provide a critical path analysis, particularly useful for complex operations. Figure 18.5 provides an example of the level of information required and how the development process is structured. It allows for further concept development and refinement before scheduling a series of tasks to be completed leading up to product launch.

As indicated in the previous section, it is frequently the case at this stage that there may be more than one design concept to be developed. In each case, concepts begin to be refined, sketches giving way to accurate drawings and provisional specifications established. Discussions with packaging suppliers are an essential



18.5 Simplified project plan presented as a Gantt chart. Most projects would require greater detail and show agreed start and completion dates.

part of the development process where suppliers often identify modifications to design concepts that contribute to production efficiencies. Inevitably, there will be negotiations at this point between designers, perhaps wishing to retain a feature and suppliers who see the same feature as a production restriction or cost factor. For example, incorporating a built-in handle on a blow moulded HD polyethylene container might be championed by designers who see it as a consumer benefit, but a supplier might view it as increasing the weight of the pack. This has penalties in terms of unit cost, transport costs and environmental performance. Here a central neck section and cylindrical configuration provide the best opportunity for reducing weight but might not meet marketing criteria or find favour with consumers. Such contradictory issues might require consumer tests to help resolve them.

It is likely that models now supersede mock-ups produced earlier. These will be to a much higher finish and will include both structural and graphic design elements. The example shown in Fig. 18.6 has been fabricated from vacuum formed plastic components, hand finished to create a realistic pack. Rapid prototyping techniques are also frequently used and specialist model makers often employed by design companies to create one-off models or, in some instances, a series of models for consumer testing. Many companies seek consumer approval of any new packaging

18.6 Highly finished model package. The concept was for a dim-sum steamer. This detailed model provides a realistic representation of how it might look. Mock-ups are not required to meet this standard of production.

design before making a final commitment to the project. Focus groups are often used where members of the public, selected to represent the target audience, are given realistic and often working models of new designs to evaluate. Depending upon the nature of the product, this may involve handling, pouring, dispensing, closing or other tasks. Feedback from consumers might result in design modifications or, more often, helping a company decide between design options. If consumer tests are required, it is important to include realistic timings in the project plan for producing models/ prototypes and to coordinate this with the market research company organising focus groups.

This stage also sees the development of secondary packaging and the evaluation of packaging performance on line and in transit. Often undecorated containers can be used for trials, although designers should be aware that, in some instances, pack performance could be affected by print. Corrugated fibreboard, for example, can suffer some slight crushing of the flutes during printing that might adversely affect performance. Production departments will normally run trials to establish filling, labelling, coding, collation, and stability on line. Transit trials can be organised using trial packs sent on representative warehousing and distribution systems. These should be designed to replicate typical conditions of pallet use, stack heights, transport methods and handling. Alternatively, packs can be evaluated using simulated package testing carried out by specialist companies. This is often quicker than real-time tests and has the advantage of being able to incorporate climatic testing, where packs can be humidity and temperature conditioned as part of the test sequence. Vibration testing can also simulate transport methods allowing the different vibrations from road, rail or air transport to be incorporated. (Pira International, a long-established company offering specialist package testing services has more information on its website, http://www.pira-international.com/Homepage.aspx.) The project plan must identify and incorporate appropriate timings for the required level of pre-production testing. Graphic development would include the extension of initial graphics from main panels onto other surfaces and incorporation of mandatory labelling requirements. The stage would see outline costs being established and would conclude with a presentation of work to the client team.

18.4 Case study: yoghurt for children

To help put the points discussed in the previous sections into context and illustrate how they operate in practice, it is useful to consider a case study. Although, in this instance, the brand is fictional, the case study is based on a real-life project. Here we only have space to show snapshots of the work at an early conceptual stage of the design process. As always, the project begins with the brief.

18.4.1 Outline brief

The company is a well-established manufacturer of dairy products and currently a brand leader in the butter market. It now wishes to establish a greater presence within the healthy food sector by increasing its portfolio of organic products. A key strategy is entry into the yoghurt market with a new range of organic yoghurts. The company has experience in this market through manufacture and supply of own label yoghurt products. This brief is particularly aimed at providing mums with a choice of healthy snacks for their children's lunchbox. The product range, under development, will initially include apple, strawberry, peach and raspberry variants in a creamy organic yoghurt base, using real fruit. Portion size will be between 80 and 100 ml and, unusually, multipacks will contain five portions (one per day). The target audience is 25–35-year-old women with young children aged 4–9. Products will be sold within the chill cabinet yoghurt section of the major multiples. The pack design must work on two levels, appealing to caring mums and engendering brand loyalty from young boys and girls.

Brand values

The butter brand is well loved in the UK and is a tried and trusted friend in many households. It is not yet readily associated with organic products but brand values are, 'friendly', 'trustworthy', 'adult', 'countrified', 'traditional'. For this project, however, a new sub-brand will be used, endorsed by the parent brand. (For reasons of confidentiality, the parent brand will be omitted from any design work represented in this chapter.)

Advertising

Previous butter advertising featured lively animated cows with some of the fun element in the ad, rather puzzlingly for an adult product, carried over to the pack design. An advertising strategy for the yogurt includes TV and magazine coverage combined with a promotion tied to the company's butter products.

Competitors

There are many competitors including those featuring franchised characters from Disney, Bob the Builder and other children's favourites.

18.4.2 The design study

At the outset of a packaging study, depending upon how broad the brief may be, the designer may have a palette of materials and pack forms to choose from. Of course, in many instances this will not be the case and the packaging project may be more evolutionary in nature, directing the designer to pack forms that, for example, can run down existing production lines without major modification. To help illustrate how the packaging design process works in practice, we can consider the approach to a case study where, in this instance, the design team is presented with a broad choice of pack forms and materials.

In this particular study, the advertising agency, a high profile multinational company, provided a two-person copywriter/designer team to work alongside the packaging designers and to contribute to the conceptual thinking. The client company provided a resource of technical and marketing assistance on demand and also presented a full range of competitor products to the creative design team. As the product had not yet been fully formulated, it was confirmed by the client that we could use natural yoghurt for trials. The in-house food technology department provided samples of the range being developed.

Research

Research begins by considering the market, expanding on information supplied by the brief as described in previous sections of this chapter. The market for children's yoghurt should be viewed within the overall UK yoghurt market as purchase is overwhelmingly carried out by adults, although children may influence the purchasing decision. Mintel International provides a readily accessible source of market data and analysis. The following information is typical of the detail provided and is extracted from the Mintel report, Yogurt – UK – May 2009 illustrated in Table 18.4. The total market for yoghurt and fromage frais has grown by 27% between 2004 and 2009 and is estimated to be valued at £1,590 million. Of this, products specifically for children represent around 18%, £275 million. In addition the report highlights some significant points, relevant to this study.

Overall, products are being positioned and repositioned in different ways to reflect market changes:

- Light/diet products are being repositioned as consumers take it for granted that all yoghurts are low fat.

Table 18.4 Leading companies and brands in the UK yoghurt market

Company	Base	Brand	Positioning
Alpro	Belgium	Alpro	Organic, Healthy diet
Arla	Sweden	Lactofree	Lactose free
		Bob the Builder	**Children**
		Mr Men	**Children**
		Scooby Doo	**Children**
Benecol	Finland	Benecol	Lowering Cholesterol
Dale Farm	UK	Spelga	Broad market
		Loseley	Extra premium
		Rowan Glen	Scottish provenance
		Intune	Probiotic
Fage	Greece	Total	Greek provenance
Danone	France	Actimel	Probiotic
		Activia	Creamy probiotic
		Shape	Hunger management
Müller	Germany	Amore	Indulgence
		Corner	Split pot
		Little Stars	**Children, natural**
		Mullerlight	Treat
		Vitality	Healthy digestion
Nestle	Switzerland	Ski	
		Munch Bunch	**Children, calcium source**
		Munch Bunch Squashams	**Children, 5–12**
		Disney fromage frais	**Children, young**
Onken		Onken Natural	Breakfast
		Onken Fruit	Treat
		Onken Wholegrain	Healthy
Rachel's	UK (Wales)	Rachel's Luscious Low Fat	Dietry
		Rachel's Greek Style	Traditional
		Rachel's Forbidden Fruits	Indulgent
		My First Yogurts	Babies
		Taste Explorers Squeezies	**Children**
		Taste Explorers snackpots	**Children**
		Natural	Breakfast
		Divine Desserts	Luxury
St Helen's Farm	UK	St Helen's farm	Goat's milk
Unilever	Flora pro-active	Lowering cholesterol	
Yakult	Japan	Yakult	Scientific
Yeo Valley	UK	Yeo Valley Smooth & Creamy	Organic, fruity
		Yeo Valley Natural	Organic, probiotic
		Little Yeo's (tubs)	**Children, organic**
		Yeo's (tubes)	**Children, organic**
Yoplait	France	Yop (bottles)	Children 10–16
		Petits Filous	Babies
		Petits Filous Frubes (tubes)	Children
		Also Co-branded promotions	
		Dr Who, High School	
		Musical,	
		In the Night Garden	
		Frubes Pouches	**Children, 9–16**

Source: Mintel, Yogurt – UK – May 2009. Brands and products in bold, indicate particular relevance to case study target market. Note that other products, fromage frais and fruit compote also compete in this market.

- Active health products (probiotics) have encountered some consumer scepticism about unsubstantiated claims.
- Organic is less important than price and is not providing benefits to justify price differentials.
- Tubes and pouches for children's yoghurts gained ground on the basis of being freezable and easily packed into lunchboxes.

Additionally, the design team also considered other market factors appearing in this and other market reports, surveys and publications, including those investigating:

- market value, seasonality, trends, brand shares
- brand values
- target audience profile, purchaser/consumer/end-user/decision-maker
- consumer requirements, in-use, storage, disposal, opening/closing
- competitor products.

The target audience had been clearly identified by the client company as young women aged 25–35 with young children (Fig. 18.7), so desk research was augmented by unstructured and informal interviews with parents of young children in this category. In this instance, the team used family, friends and parents at a local school.

Clearly, the healthy lunchbox was seen to be a key factor currently driving the market. Although Mintel reports that tubes were gaining market share, most mothers, however, were not in favour due to the mess tubes could cause on opening. They favoured conventional rigid pots where the contents can be eaten with a spoon. Any floppy pack form was less favoured, especially if it could not be resealed. Experience of children snacking in the car convinced parents that the child/tube interface was not controllable. School staff echoed this view through their experiences during school lunch breaks. Some parents, however, disagreed and were of the opinion that if packs could be resealed some children would not finish their yoghurts.

18.7 The target audience in the case study represented by a mum and two children of school age.