

8.20 Swage top of aerosol can.

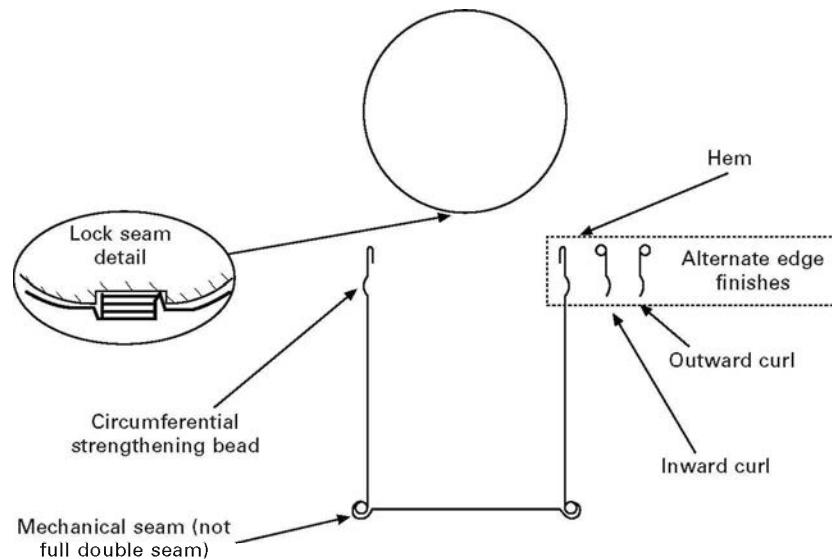
### 8.3.5 Mechanical lock seam for general line decorative cans

The bodies of made-up general line containers are constructed from two or more pieces of pre-decorated tinplate with an almost infinite variety of cross sections available, ranging from round, oval and rectangular to triangular, hexagonal, etc. The body side joint is made by creating a lock seam where the edges of the metal are folded and pressed together. As these containers are not required to hold liquid, there is normally no cement or compound in the lock seam or the end seams. For special cases such as highly decorated cans for paint, it is possible to apply a hot melt adhesive to the seam faces prior to forming the lock. This will produce a liquid tight seam.

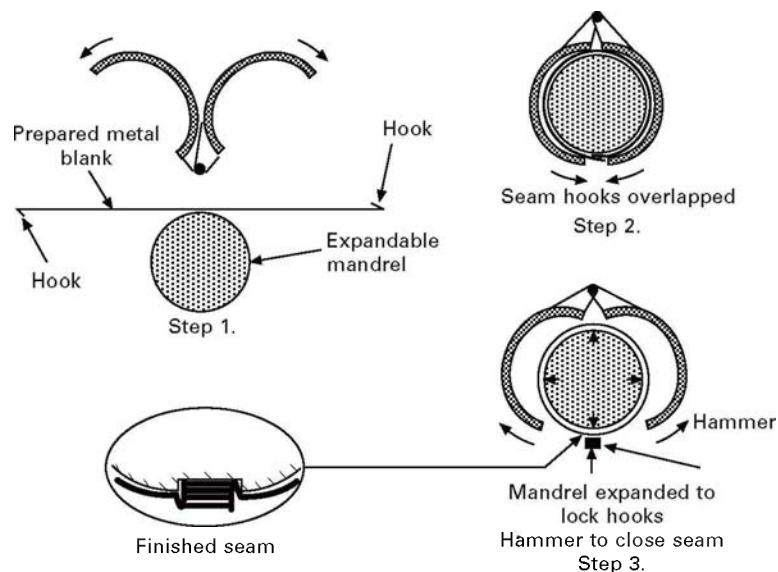
A typical made up container has a parallel wall body with a partly formed flange at the bottom to accept a mechanically seamed flat panel end. At the open end of the can, the top edge is hemmed or curled (internally or externally) to make safe the raw edge of the metal and provide additional strength across the section. This type of container is described in Fig. 8.21. Where the walls are to be embossed, the design is formed in the metal while the blank is still flat and before any other operations have been performed on it.

The principles used in forming and lock seaming the body are the same for all cross sections, but the tooling which forms the cross section is specific to each different can design. The edges which will form the seam must be hooked, as shown in Fig. 8.22 before the cross section of the body is formed. Provision of these ensures that the body does not spring open after the cross section shape has been formed. Figure 8.23 shows the process flow diagram for the general line lock seam can:

- Step 1 A prepared metal blank is fed into the machine and placed equidistant across the expanding mandrel.
- Step 2 The forming fingers close around the blank, forming it to the shape of the mandrel in the non-expanded position. At this point, the two hooks on the opposite edges of the plate loosely interlock.
- Step 3 The forming fingers open up and the mandrel expands to pull the two edge hooks tightly together and give the correct internal dimensions to the can. At this point, the seam is hammered flat to provide a positive lock.



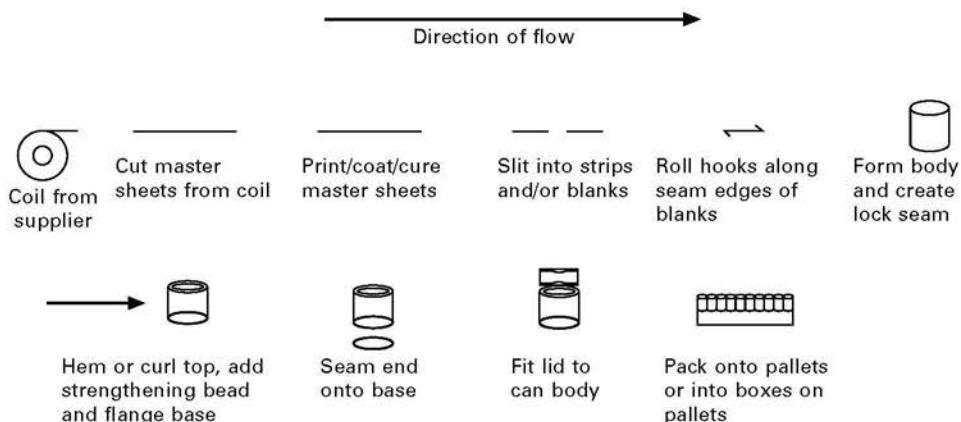
8.21 General line non-performance can. Courtesy of Pira International.



8.22 Forming and lock seaming general line can. Courtesy of Pira International.

### 8.3.6 End making processes

Can ends for mechanical double seaming are constructed from aluminium, tinplate or tin-free steel (TFS). Aluminium and TFS are always coated on both sides with organic lacquer or film laminate whilst the metal is still in coil or flat sheet form.



8.23 General line lock seam process flow.

For tinplate these coatings are optional, depending upon the product being packed in the container and the specified external environmental conditions.

The base of a three-piece can will always be a plain end (non-easy-open). For food cans, the top may be either plain (requiring an opening tool), full aperture easy-open or peelable membrane design. Historically, tapered rectangular solid meat cans have employed a key opening device to separate the two scored body sections; these are now gradually being replaced by containers having rectangular panel full aperture easy-open ends. For drink cans, the top is usually referred to as a stay-on-tab (SOT), enabling the opening tab and pierce-open end section to be retained on the can. The SOT end has largely superseded the traditional ring-pull end.

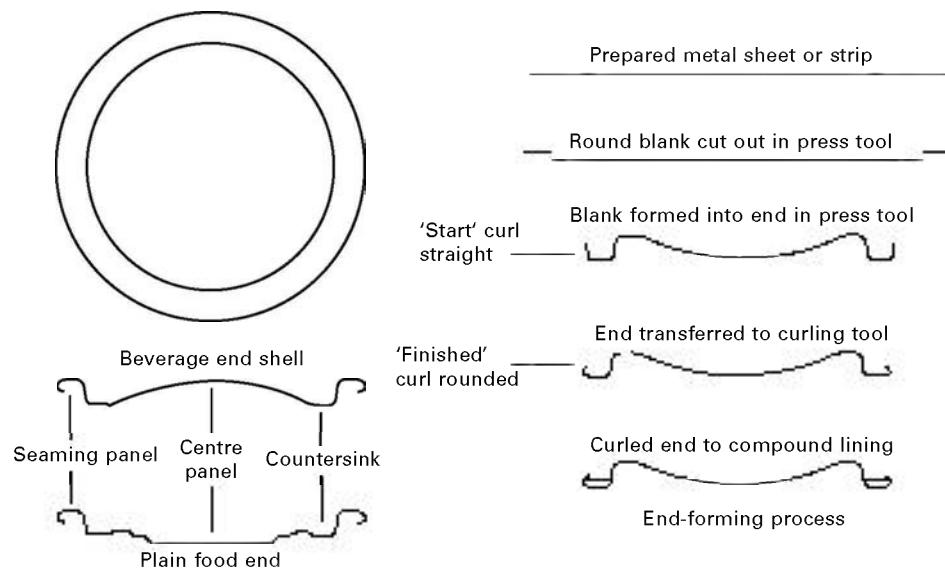
All ends for processed food cans have a number of circular beads in the centre panel area to provide flexibility. These allow the panel to move outwards, as internal pressure is generated in the can during the heating cycle of the process and so reduce the ultimate pressure achieved in the can. During the cooling process, this flexibility permits the centre panel to return to its original position.

Ends for beer and carbonated drink cans do not require the above feature as the can's internal pressure is always positive. The plate thickness and temper have to be appropriate to the level of carbonation of the product and, if applicable, pasteurisation treatment; otherwise excessive internal pressure may cause can ends to peak or distort.

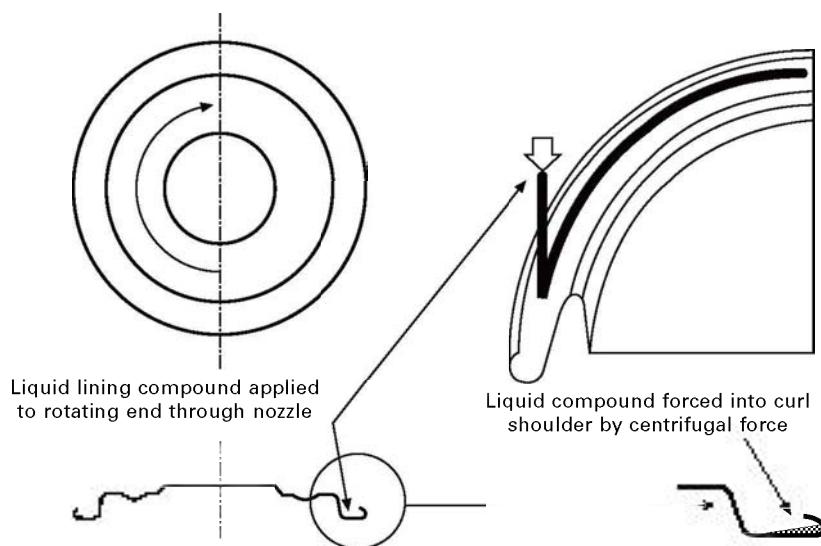
#### *Plain food can ends and shells for food/drink easy-open ends*

The initial processes for making plain food can ends and easy-open ends for food and drink cans are the same. The body of an end that will ultimately be converted into an easy-open end is referred to as a shell. Plain ends/shells may be stamped directly from wide coils of metal or from sheets/strips cut from coils. When using coil or sheet, the metal is fed through a press that produces multiple stampings for every stroke. After removal from the forming tool, the edges of the end shells are then curled over slightly to aid in the final operation of mechanical seaming the end

onto the flange of the filled can. After curling, the end shells are passed through a lining machine that applies a bead of liquid-lining compound around the inside of the curl. This process is described in Fig. 8.24. The compound lining is a resilient material that, during mechanical forming, will flow into the crevices of the double seam and thereby provide a hermetic seal. The application of this compound is shown in Fig. 8.25.



8.24 Plain food end and beverage end shell forming. From Coles R et al., *Food packaging technology*, 2003, Blackwell. Courtesy of Blackwell Publishing.



8.25 End lining compound application. Courtesy of Pira International.

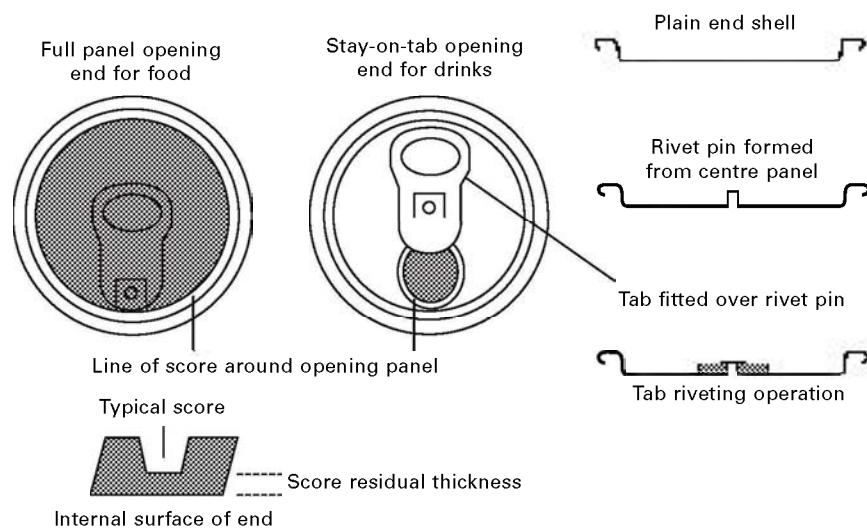
### Conversion of end shells into easy-open ends

The principles used in the conversion of end shells are the same for both full aperture food easy-open ends and small aperture drink easy-open ends. The conversion operations comprise scoring (partially cutting through) the perimeter of the opening panel and attaching a metal tab with which to tear open the panel. These operations are described in Fig. 8.26. Scoring is necessary to reduce the force required to open the end to an acceptable level and to determine where the break will occur.

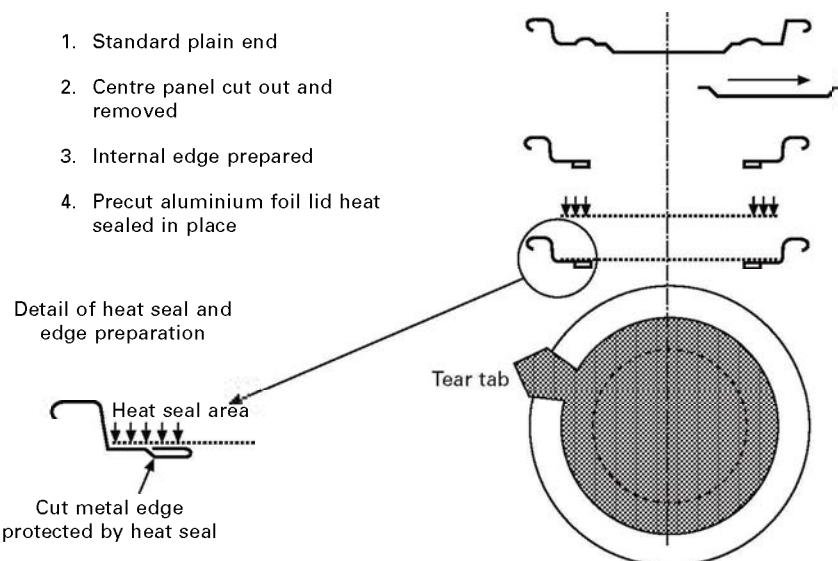
The pull-tab is made from a narrow strip of pre-coated aluminium or steel, which is in coil form. The strip is first pierced and cut, and then the tab is formed in two further stages. At this point the tab is still attached to the strip by bridges to facilitate feeding over the rivet formed in the shell. The shells pass through a series of dies that score them and form a hollow upstanding rivet in the centre panel of the shell. The tab is then placed over the upstanding rivet on the shell, and the rivet is deformed to make a joint between the two components. The finished ends, ready for capping the filled cans, are packed into paper sleeves and palletised for shipment to the can filler.

### Peelable membrane ends for food cans

A peelable membrane end is essentially a plain aluminium or steel food can end with part of the centre panel removed as a disc and replaced by a pre-cut aluminium or polymer membrane which is heat sealed to the remaining part of the centre panel. Figure 8.27 shows the assembly of this end from which it will be noted that the cut edge remaining after removal of the disc is folded back on itself so that the raw



8.26 Conversion of plain end/shell into easy-open end. From Coles R et al., *Food packaging technology*, 2003, Blackwell. Courtesy of Blackwell Publishing.



8.27 Peelable membrane end. Courtesy of Pira International.

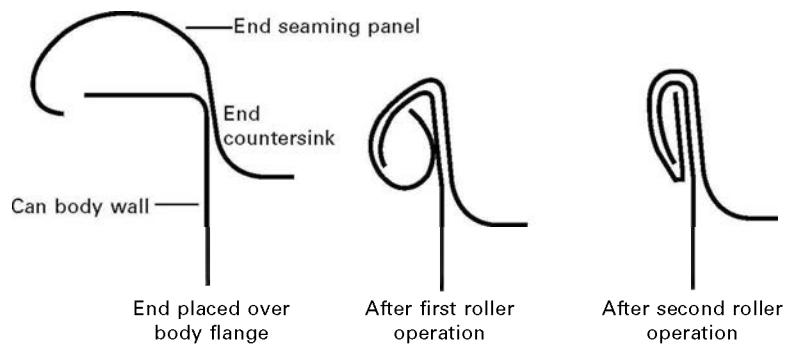
metal edge is protected within the heat seal area. A recent design of this type of end is capable of withstanding full heat processing conditions without the need for overpressure in the retort to prevent rupture of the membrane due to high internal pressure.

### 8.3.7 Mechanical seaming of ends onto can bodies

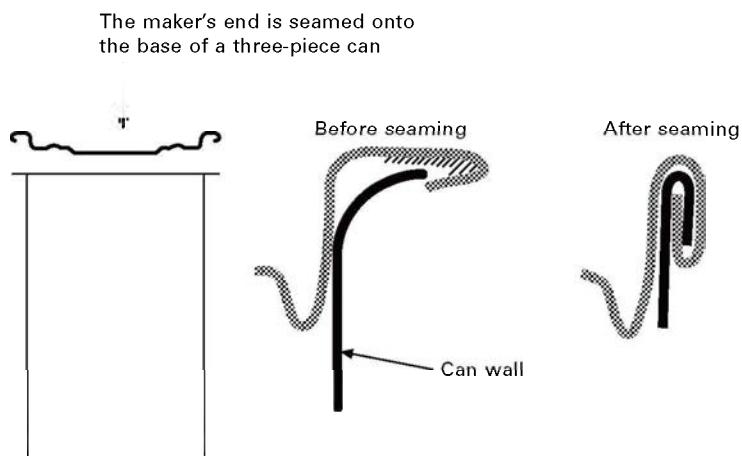
The standards employed during the process of mechanical double seaming ends onto can bodies are extremely important in ensuring the ongoing safety of the product packed into the container as, after heat processing and cooling is completed, the internal pressure in the can is negative. As a consequence of this, any weakness in the double seam could lead to micro leaks and the introduction of non-sterile air into the container. Industry standards are designed to ensure that practical interchangeability is achieved when end and can components are purchased from different sources.

The basic system of double seaming described below, originally established at the start of the twentieth century, is the same for food, drink and aerosol cans and is applied to both round and non-round ends. The seaming tools have to follow the profile of the can/end cross section; this allows round profiles to be seamed more quickly than, say, rectangular profiles.

Figure 8.28 describes the sequence of the loose end being offered up to the can flange and the two seam roller operations to create the finished seam. The inside diameter of the end curl is just sufficient for it to drop cleanly over the flange of the can. If the end were not curled the two components would not lock together as the seam was made. During the seaming process, which is in two stages, the end is mounted on a round (or non-round) chuck which fits the external surface of the countersink wall and supports this wall during the seaming process. The first stage



8.28 Mechanical seaming operations. From Coles R *et al.*, *Food packaging technology*, 2003, Blackwell. Courtesy of Blackwell Publishing.



8.29 End mechanical seaming – overview.

external roll rotates the seaming panel of the end with the can flange to close them up as shown. The second stage external roll tightens up the seam to give the correct final external dimensions and produces the required hermetic seal. Both first and second stage operations are carried out in the one seaming machine. Figure 8.29 provides an overview of this process.

The cross-section view of a finished double seam is shown to the right in Fig. 8.29. To evaluate the seam, some of the dimensions can be taken from the outside of the finished seam while others can only be measured from a cross-section view. This view may be obtained either by cutting through the seam or by using X-ray technology. Some parameters cannot be measured directly from the seam cross section but require simple mathematical calculation to deduce the result.

### 8.3.8 Basics of heat processing of food (retorting)

For long-term storage of canned food products at ambient conditions, it is necessary to kill all living organisms within the can after filling and seaming on the closure.

This is achieved by sterilisation using heat. To complete this process so that food safety issues are completely satisfied, it is necessary to ensure that all the product in the can has received sufficient heat for the required minimum amount of time. For liquid products, convection currents within the can allow more rapid temperature increase time than, for instance, solid products where heating up the centre core of product may only be achieved by conduction.

The operating principle of the heating method used is similar to that of the domestic pressure cooker. In this process the cooker is allowed to operate at an internal pressure somewhat higher than normal atmospheric pressure. A pressure relief valve fitted to the lid controls the internal pressure and prevents it rising above this level. This elevates the boiling point temperature of the water in the cooker which in turn reduces the overall time required to heat the food to the required temperature. Industrial retort systems operate in a similar way but at higher pressures and temperatures to ensure the correct sterilisation temperatures are reached. In these systems, achieved temperatures will usually be in the range 113–132°C with processing times ranging from five minutes to periods in excess of one hour, depending on the type of product being sterilised and the can dimensions.

Industrial equipment generally falls into one of two basic types: static retorts, which are larger versions of the domestic unit or continuous retorts, where filled cans enter and exit the retort in a continuous stream. The pressures inside industrial retorts will vary between approximately one and two atmospheres above the external ambient pressure depending on the retort temperature, the higher pressure giving the higher temperature. The varying pressure and temperature experienced by the can during the heat process causes severe physical loadings on the can body and end. This needs to be understood to ensure the container is capable of withstanding these without collapse.

When the can enters the retort its contents are usually only warm, having sufficient heat to aid in conveying and filling the product into the can, and the internal pressure is atmospheric or slightly below if vacuum packed. As the full steam pressure acts on the outside of the can, the pressure imbalance has the effect of imploding the can body. This force is only resisted by providing the body with sufficient hoop strength (usually by the addition of circumferential beads) to supplement that provided by the product itself.

When the temperature inside the can ultimately reaches that of the steam on the outside, the pressure in the can has become greater than that of the retort chamber. This is because the total can internal pressure is the combination of the thermal expansion from the increasing partial pressure of the water in the product, plus that of the expanding headspace gases.

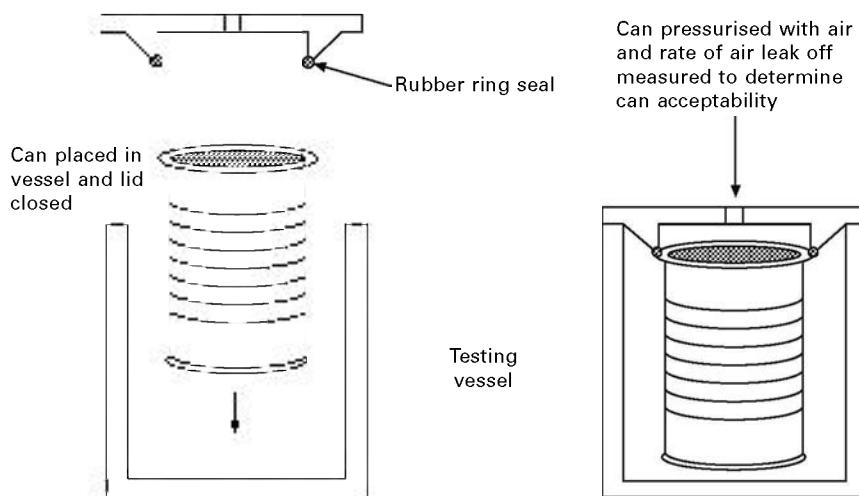
At exit from the process the contents are still relatively hot but the external retort pressure is reducing and the can is now trying to explode. At this point the can ends are temporarily deformed outwards in resistance to the internal pressure load. As the can and contents slowly cool down to room temperature, a negative pressure is induced inside (as the contents were originally warm when the end was seamed on). It follows that, for a processed food can at ambient conditions, the contents provide only a relatively low level of physical support to the can wall. This is in contrast to

the high level of wall support provided by the pressurised contents inside a beverage can.

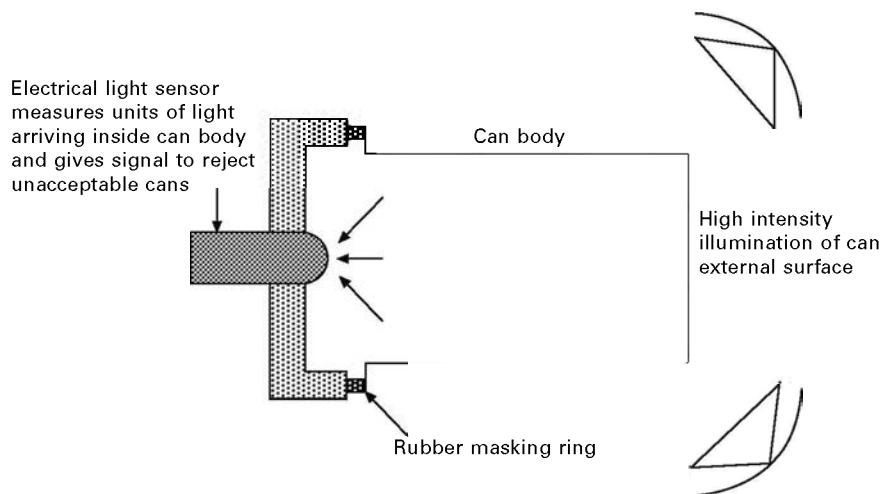
Whilst the end is primarily designed to resist the high relative internal pressure achieved towards the end of the process, it must also be sufficiently flexible to return permanently to its original profile as the internal pressure becomes slightly negative. If this does not happen, the can may have the appearance of being blown with the product wrongly being deemed unfit for use by the consumer. For very lightweight containers and those having flexible heat sealed lid systems, an over-pressure retort will allow the retort chamber pressure to be controlled so that the physical loads on the container and end are insufficient to cause damage or rupture.

### 8.3.9 Quality assurance of semi-finished and finished components

Quality assurance checks on semi-finished and finished components are carried out both in-line, as part of the manufacturing process, and off-line in a laboratory. Some in-line processes such as pressure or light testing for cracks and pinholes, video inspections of can internal surfaces or external decoration, are part of the manufacturing process and are carried out on every component produced. Figures 8.30 and 8.31 describe the principles of in-line air and light testing, respectively. Most other checks use predetermined sampling plans where components are removed from the line either automatically or by hand. Statistical analysis is then used to determine the performance of the various processes. This method of control is required because the line production rates are so high, being in the range 50–2500 items per minute. For dimensional checks, automatic measuring stations are often used. These stations may be situated in the production area and may be fed with sample components automatically or by hand. The equipment produces the results of each sample in a statistical format and delivers the results to the central laboratory.



8.30 Three-piece can air testing principles. Courtesy of Pira International.



8.31 Two-piece can light testing principles. Courtesy of Pira International.

The following are examples of off-line tests usually carried out:

- Dimensions – height, diameter, wall thickness range, flange width
- Strength – axial compression, resistance to implosion (food cans), base dome buckle (drinks cans)
- Coating integrity – weight, continuity (freedom from pinholes), adhesion
- Ends (in addition to above tests), deflection due to internal pressure changes, lining compound placement and weight
- Easy-open ends, additional tests to determine ‘pop’ and ‘pull’ loads to open and tear the tab, rivet strength and integrity.

Attribute sampling is normally carried out on randomly selected pallets of finished cans or ends before these are conveyed to the warehouse for onward shipment to the customer. A sample plan is devised so that, for example, in a pallet containing 5,000 cans, six cans will be removed from the outside rows each from a different layer. These will be closely examined by eye. If more than one of these samples is deemed not fit for purpose, then the whole pallet will be quarantined for further checks. At the same time the pallets preceding and following this will also be checked in the same way until enough pallets have been held to ensure that the incidence of the problem has been contained.

Traceability of raw materials through to the finished components is assured by the recording of the coil numbers, or sheet pallet numbers where these are used, and time over which these are fed into the production line. Likewise container or batch numbers of coating materials are recorded in the same way. These references then tie up with the serial numbers of the finished pallets of components. Bar codes are generally applied to the labels on pallets of finished goods to give both fixed information such as customer name, container specification, number of items, etc., and real-time information such as pallet serial number, date, time pallet packed, etc. For drinks cans externally printed in-line, a code is embodied into the label

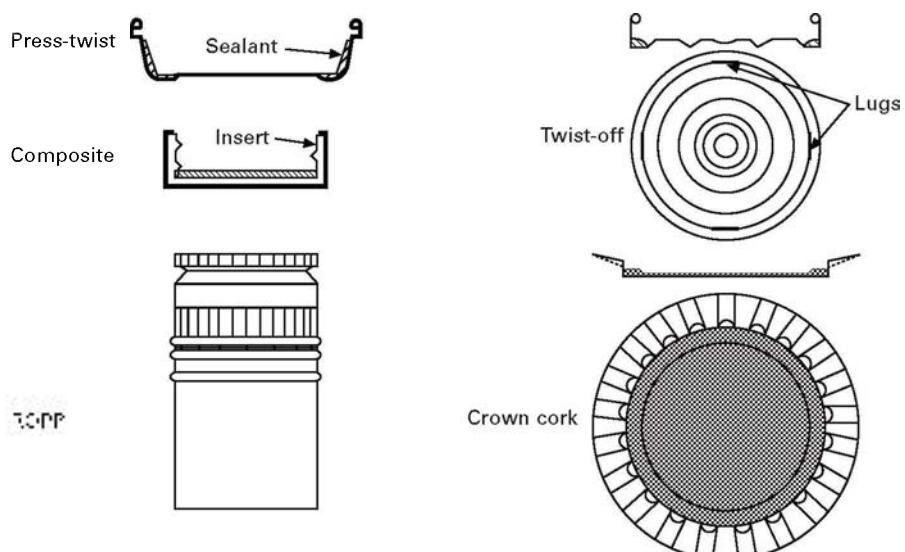
design, at the overlap area which indicates the makers name, factory, date and shift of manufacture.

The most common defects that may be found in metal packaging components are:

- all can bodies – low tin coating weight, badly formed flanges
- coated surfaces – pinholes, poor adhesion, undercuring, underfilm staining, cracks in coating after necking in drink cans and after curling can ends
- three-piece can bodies – poor weld strength, badly formed/incomplete weld
- two-piece draw and wall ironed can bodies – pinholes in body or flange area
- can ends (plain) – lining compound incorrect weight and bad placement
- can ends (easy-open) – broken/leaking rivets, residual score out of specification, pop and pull loads out of specification.

## 8.4 Metal closures

Metal closures for fitting to glass and plastic containers are highly specialised products. Because of the different strength requirements, the closures for drinks containers are made from aluminium, whilst those for processed food are made from steel. It will be seen that the threads on closures can be formed during the initial metal-forming process, or as an off-line moulding process, or during the filling/closing process or even during the (food) heat processing operation. In all cases, the dimensions (finish) of the neck of the glass/plastic container need to be specified very accurately and, for this reason, the specifications are usually set by the closure manufacturer and not the container maker. Outlines of all the closures discussed below are shown in Fig. 8.32.



8.32 Outlines of metal closures.

#### 8.4.1 Roll-on pilfer proof (ROPP™) caps

Roll-on closures are made only from aluminium, because it is necessary to have a soft material for the thread rolling process. This type of closure is initially produced as a printed and internally coated deep drawn two-piece can. After the addition of special mechanical features, and a wad or flowed-in liner to provide the seal to the surface of the bottle, the closure is complete and ready for shipment to the filler. When the bottle has been filled, the closure is slipped over the neck of the bottle and the threads are rolled into the closure to conform to the profile of the neck of the bottle.

The manufacturing process for the roll-on closure is the same as that for a draw/redraw can made from printed and coated sheet aluminium. If the end of the closure is to be printed, this is done whilst the metal is still flat. The closure liner is either a wad cut and inserted into the metal shell, or a flowed-in polymer applied to the inside top surface of the shell. Where the latter is used, the flowed-in material can be applied over the whole of the inside top surface or just to the circumference.

#### 8.4.2 Composite closure

A composite closure comprises 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 low density polyethylene plastic insert has internal threads moulded into the side walls and is designed to accept a standard wad liner. This type of closure can be made with or without a tamper evident feature.

A composite closure provides two additional features to the standard ROPP™ closure.

- The thread of the closure is internal and provided by the insert, so that the external side wall of the closure has no threads in evidence after it has been sealed onto the bottle. This closure is used to improve the external appearance of the filled package.
- As the internal thread of the closure is made from moulded plastic, it is more suitable for use with products which have a high sugar content, such as liqueurs. When an all aluminium closure is used with these products, there is a tendency for the sugar, which remains on the thread after the bottle has been used for the first time, to form a sticky deposit between the aluminium and glass threads. This makes the bottle difficult to re-open. When one of the thread components is made of plastic, this problem does not occur.

#### 8.4.3 Twist-off closures

Twist-off lug closures, which require less than one turn to apply and remove, 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. The product inside the glass jar is packed under vacuum, by packing the product hot and flushing the headspace with steam; the vacuum increases as the product cools to ambient temperature. The seal

between closure and the top face of the glass jar is produced by a combination of the internal vacuum and the mechanical force produced when the cap is tightened in the capping machine. Many twist-off closures are now fitted with 'vacuum buttons' which indicate to the consumer, prior to opening, whether there is still vacuum inside the headspace. The internal vacuum produced during the packing operation is sufficient to pull down the vacuum button. For the light metal packaging industry, the combination of a twist-off closure fitted to a glass jar is unique, it being the only time that a fully preformed metal component is fitted to a fully preformed container made from a non-metal product.

#### 8.4.4 Press-twist (PT) closures

The high volume market for heat processed baby food in glass jars necessitated the development of a high-speed closing system for the filled package. The PT closure, which was developed for this market, needs only to be pushed over the threads in the neck of the glass jar to make the initial closure. The heat of the processing system does the rest, by softening the sealant and allowing it to flow into the threads in the neck of the glass jar. A vacuum button is created during the metal-forming operations to indicate to the consumer, prior to opening, whether there is still vacuum inside the headspace. In the UK, a plastic moulded tamper evident ring is often incorporated into the closure. This is held in place by a curl on the wall of the closure.

#### 8.4.5 Crown cork closures

Crown corks are used for sealing glass bottles containing carbonated or non-carbonated drinks. The cap is pre-formed during the manufacturing process and clinched onto the top of the bottle manually or automatically after the bottle has been filled. A tool is required to remove the closure from the bottle, which may be hand held or wall mounted. This closure is manufactured from tin-free steel with suitable coatings on both the inside and outside. The process is identical to that used for plain can ends until the press-forming operation. At this point, the blank is cut from the sheet in the same press station where the cap is formed. After forming, a liner is introduced into the top of the cap to make the seal across the top of the neck of the bottle.

### 8.5 Cost/performance comparison: raw materials and forming processes

The cost of the metal represents some 60–70% of the manufacturing cost of most metal packaging and is therefore the most significant element in total product cost. The only exception to this is where highly decorated containers are made for general line promotional markets where the decorating cost percentage is significantly more than for, say, food or drink cans. In this case the metal cost will fall to 40–50% of the manufacturing cost.

The purchase price of metal, whether steel or aluminium, is related to the amount of work (gauge reduction) undertaken by the metal manufacturer. This means that the

price per tonne increases as finished thickness is reduced. While this still translates into a net reduction in price per unit of metal area purchased for each step of thickness reduction, the underlying increase in price per tonne offsets some of the potential price reduction from the reduction in gauge.

The above scenario becomes important when comparing the cost of the metal used in making three-piece welded and two-piece drawn and wall ironed (DWI) cans for processed food. In the three-piece can, for each step of gauge reduction the cost of the metal to make the body will reduce as described above, as here the metal is used in the condition received from the manufacturer with no change to thickness or properties through the can-making process. In the DWI can, which starts with heavy gauge metal to give the correct base thickness, the can-forming process does the additional work on the metal to reduce the wall to the required final thickness. A reduction in wall thickness is produced solely from a reduction in the diameter of the disc cut from the coil as the result of a change in tooling dimensions. The thickness of the metal coil purchased does not have to change for this to happen. As the disc diameter is reduced, so is the width of metal coil reduced to keep the web scrap to a minimum. This also reduces the area of metal purchased for each can. In summary, for downgauging the wall of a DWI can, the price per tonne of the purchased metal is unchanged and the reduction in wall thickness is produced solely from a change in tooling dimensions. Thus, for the same wall gauge reduction step, the DWI metal cost reduction will be greater than that for the equivalent three-piece can.

Comparing the relative prices of steel and aluminium metal for packaging is very difficult because aluminium metal is a traded commodity and often must be purchased in bulk, in advance. This can create major price variations. Steel prices, on the other hand, are generally much more stable and are normally subject to annual review to reflect cost changes. Prices of both metals are, however, subject to global political situations. On a like-for-like basis, aluminium is generally more costly than steel for packaging but the value of waste material generated from the can-making operations is significantly greater for aluminium than for steel processes. The greatest competition between these two metals is for DWI drink cans and the drink can fillers like to keep healthy competition between the two metals!

Aluminium is inherently less strong than steel, so this limits where aluminium may be economically used for the construction of metal packaging. Also, as stated in Section 8.3.1, aluminium cannot be used for making three-piece welded side seam containers. On the other hand, steel can be used to make all types of metal package except where impact extrusion is employed for forming the two-piece seamless body, because steel is not soft enough to respond to this particular forming process.

Uses and restrictions for both aluminium and steel for construction of metal packages are shown below:

- Aluminium is used for pressurised containers where the internal pressure generated by the product gives additional strength to the can wall, for products such as beer and carbonated drinks in DWI cans, and also for seamless aerosols and collapsible tubes. It is used for shallow or short drawn cans for processed foods such as fish and pâté. (Economic wall strength is not sufficient to withstand full heat process conditions in tall food cans.) Aluminium is used for roll-on pilfer

proof caps where the metal must be soft to take up the shape of the underlying bottle thread.

- Steel may be used for all metal packaging formats except those using the impact extrusion process and roll-on pilfer proof caps. ECCS (tin-free steel) cannot normally be used for welding as the chromium surface is not compatible with the welding process (special systems have been used for first removing the chrome from the steel surface but these are not very practical). ECCS can only be used for DWI cans when extruded polymers have first been applied to the metal surfaces. However, these processes are still in the development stage.

When comparing the various can-making processes and in particular three-piece welding with two-piece DWI, which together form the bulk of all cans produced, the following points need to be considered:

- The three-piece welding is a very flexible process allowing cans of different height and/or diameter to be produced from the same system, although to make different diameters there needs to be investment in appropriate tooling. In addition, facilities for coil cutting into sheets, sheet coating/printing/curing and sheet slitting need to be provided upstream of the can-forming equipment.
- Two-piece DWI can making is relatively inflexible and the process runs at its most efficient if the same size of can is made continuously on a 24 hour/day, 7 day/week basis. Lines may be constructed to make small changes in can dimensions. To suit this process, the market for the can output needs to be in the order of 600 million per annum. There is no need for coil cutting, with coating/printing (where appropriate) carried out as in-line processes. Under these conditions and assuming cans of similar dimensions and wall thicknesses, the metal cost of the tinplate DWI can should be slightly less than that of the equivalent tinplate welded can with the maker's end fitted.

## 8.6 Container specifications

Specifications for containers, ends and closures are necessary to ensure that the filled package is capable of fulfilling its required duty and continues to do so within acceptable ranges for all ongoing supplies until the end of a supply contract or until changes have to be made to reflect new requirements. Development of a container manufacturing specification and therefore manufacturing/delivery cost starts when the user/filler defines the performance criteria. This will contain the following information:

- type of product to be packed and shelf life expected (this will indicate whether this is a dry or wet product, what type of heat processing, if any, may be required and what filling method will be employed)
- portion size/volume contents plus headspace
- label system (printed container or paper label)
- preferred can opening method
- annual quantity required and location of customer warehouse/filling line
- system for packaging and transporting the empty containers and ends.

From the above data, it should be possible to select the container overall dimensions, the most appropriate container forming system and the type of metal to use for the container and ends. This will also dictate the label system and the empty container/end packaging system.

From the detail of the product and metal types selected, together with heat processing systems and shelf life requirement, physical strength conditions can be defined. The specifications and applied weights of organic coatings can also be derived at this stage. When the physical strength properties are known, the can maker is able to calculate the thickness and detailed specification of the metal to be purchased as well as the thickness of the can body walls and ends. Only at this point is the can maker able to calculate the cost of the metal used to make, say, 1,000 containers. Following this the manufacturing and transport costs may be computed.

Purchasing specifications for metals and organic coatings are developed from the above data. The purchasing specification developed by the filler customer will include details of quality assurance tests to be performed by the can maker together with limits of acceptance and how to handle disputes. It will also contain advice on how containers are ordered, what call-off systems are employed and whether deliveries are to warehouses or direct to filling factories. Methods for acceptance and signing off of print quality will also be included.

The basic type of information that will be included in metal container specifications is shown below:

- Can body:
  - Construction method, metal type and specification
  - Dimensions: nominal body diameter, neck diameter (if reduced from that of body), flange diameter(s), open top can height
  - Volume capacity: gross lidded volume
  - Physical performance criteria, strength
  - Surface coating specifications, application weights, performance criteria
- Can end:
  - End type, metal type and specification
  - Dimensions: nominal diameter, outside curl diameter, curl height, countersink depth
  - Physical performance criteria, strength (pop and pull opening loads for easy-open ends)
  - Surface coatings/lining compound specifications, application weights, performance criteria
- Can body and end:
  - Attribute levels of acceptance and other specific quality assurance requirements agreed with customer
  - Secondary packaging specification, barcode identification specifications.

The list of specification requirements given above are just the basic requirements. Reference may be made to meeting the requirements of national or international specifications. In the case of drink and processed food cans, specifications may include the need for achievement of practical interchangeability between, say, can

ends and the flanges on can bodies to ensure ongoing satisfactory mechanical seam performance, particularly when these components are purchased from multiple supply sources.

### 8.7 Decorating processes

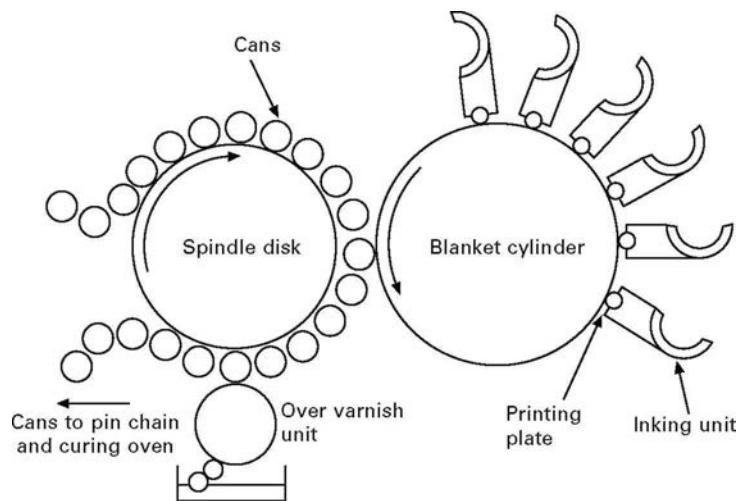
Printing on metal packaging provides decoration to attract the consumer and reinforce the image of the product brand while also giving information about the package and its contents. (See also Chapter 19 for a detailed discussion of printing for packaging.) Printing on to metal for packaging may be undertaken with the metal in flat sheet form, prior to metal forming (for three-piece, general line lock seam and drawn containers), or after the circular body has been formed in the case of DWI or impact extruded containers. Flat sheet printing allows an unlimited number of colours to be laid down, regardless of the number of printing machines/colour heads installed, because sheets can be re-fed through these machines for additional colours to be added. When printing on circular bodies the maximum number of colours is determined by the design of the machine.

The printing techniques employed for flat metal sheet are very similar to those employed for paper and board. Conventionally wet lithography has been the most common way of laying down the print on flat sheets but this is being replaced by the use of waterless plates (Toray system). This process requires good temperature control of the inks but has the benefit of being more ecologically friendly in no longer using alcohol for damping. The improved temperature control reduces the number of wasted sheets at start-up. However, once the ink has been laid down on the surface, the unique properties of metal become apparent in that metal:

- is hard and allows a very clear image to be formed
- may have small quantities of preservative oil on the surface which is not washed off before printing (or coating)
- is not absorbent, so all liquids on the surface must be removed by evaporation
- may be cold and may therefore have condensation present
- if tin plate, has a tin layer which melts at 232°C, being only some 25°C above the curing temperature of many coatings.

The other major difference is that metal sheets are relatively heavy, so handling systems in printing equipment have to be modified to cope with this.

Techniques for printing on formed circular bodies have to overcome the restriction that it is not possible to register individual colours onto a continuous surface. This issue is solved by first laying down all the colours in sequence, as a reverse dry offset image, on an intermediate rectangular surface (rubber blanket) which has the same dimensions as the external surface of the container. This surface is then brought into contact with the can and the whole image is rolled around the outside to effect the transfer. This operation is described in Fig. 8.33. Digital technology is now being developed and brought into production for circular printing of drinks cans. This will allow virtually instant change of design to take place with no set-up time or wastage of ink and containers. It will also permit topical information to be included on can



8.33 Cylindrical can decorating machine. Courtesy of Pira International.

label designs for sale of filled product within say 24 hours of the can being made. Inks for both flat sheet and circular print systems are available in heat cure or UV forms. The same restrictions of use apply as are described for organic coatings in Section 8.2.4.

For small-sized containers, it may be difficult to contain all the required information in the side wall of the container. For other containers the presence of product data on the side wall may detract from the overall image which the marketer is trying to convey. In these situations some of this information may be printed on the base of the container. For three-piece and lock seam general line containers this is straightforward. For two-piece containers, including closures, the need to have print both on the base and the side walls presents additional challenges. The only way to achieve this is to print the side walls and the base whilst the metal is still flat, prior to the first forming process. As the walls will be reformed during the drawing operation, any print placed on the flat blank outside the area of the base will become distorted. In addition to this, the further the print is placed up the side-wall, from the base of the container, the more it will be distorted from the original design. In order to overcome this problem, the design of the print for the walls of the container or closure is pre-distorted at the original design stage. Then, after the metal forming operation is complete, the print appears in its correct form.

## 8.8 Environmental overview

There has always been a great emphasis on reduction of metal used at source in can-making operations because, as already mentioned in Section 8.5, the value of the metal used is generally in the order of 60–70% of the manufacturing cost. Metals for packaging are mostly purchased by area which makes it possible to closely align purchase quantities with those actually used. For the same reasons, over the years, many developments have been introduced across the industry to minimise material waste

from offcuts, web scrap and finished product scrap. Lightweighting has additionally also been ongoing for many years, alongside technical process improvements. The introduction of the DWI can for drinks and later processed foods is one of the main drivers in this, together with other processes where high throughput speeds and high efficiencies can be achieved. Data recently released by EMPAC (European Metal Packaging, 2009) demonstrate that over the last 20 years the market for food and drinks cans, in steel and aluminium, has increased by 57%. Over this same period the absolute quantity of virgin metal used has reduced by 20%, and net CO<sub>2</sub> emissions and net energy usage have reduced by 50% and 60%, respectively. To maintain and improve on this excellent record, it will be necessary to increase the percentage of containers recycled into new metal from sources of post consumer waste.

Recycling of waste materials arising from the can-making process into new metal has been a very high priority for many years because these materials have inherent value in the economics of these processes. Metal packages are less easy to reuse than some other packaging materials, but recycling used metal packages into new metal is very straightforward. Metal is different from other packaging materials like paper and plastic because metals (steel and aluminium) are recycled on an atomic level. This means that once re-melted, recycled metal is indistinguishable from new metal smelted from ore and these metals may be re-melted an infinite number of times without loss of properties. This material property makes it a unique packaging material. During the re-melting process minor contaminants such as tin, organic ink and coatings, as well as other organic residues, do not cause any problems in the steel-making itself. Gaseous effluents arising from these are contained within the steel-making process. In some cases tin is reused in the packaging steel-making process. It may also be removed from tinplate scrap by a system of reverse electroplating. In the steel-making process commonly used for packaging steel, steel scrap from packaging and non-packaging sources is needed to control liquid iron temperature in a converter during the exothermic reaction of carbon reduction by flushing with oxygen.

Recent studies on sustainability of metal packaging confirm that an increased recycling of post consumer metal packaging waste after end of life reduces the amount of new metal that needs to be produced as virgin material. Furthermore, the use of recycled metal is infinitely more beneficial in the reduction of CO<sub>2</sub> emissions than the reduction of energy, transport or metal usage in container manufacture and delivery. With metals, the energy used in the mining, transportation of raw materials and smelting operations to produce new metal from ore is locked up in the metal forever, to be used in a next material life, whatever it is used for.

One of the main environmental benefits arising from fresh food packed into metal cans which are then heat processed is that the pack is then stored at ambient temperature for the remainder of its life. Metal packaging has excellent barrier properties – 100% protection from light, air and water – ensuring maximum product quality. Products packed in metal do not require additives to preserve them.

Canned food may be stored for years, no further energy being required purely to preserve the integrity of the product. In many underdeveloped countries, vast quantities of agricultural products go to waste because they have become inedible before they

can be consumed. Preserving these products by packing into heat processed metal containers at source can provide a satisfactory solution to this issue. Furthermore, it does not matter how far away the final customer is located from the original source of the fresh product or how long it takes to arrive, as the contents, once opened, will still be fresh with no additional energy required to keep it so.

## 8.9 References and further reading

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**Abstract:** This chapter reviews the manufacture and use of aluminium foil as a packaging material. It discusses processing from refining and smelting to the production of foil, printing and embossing. The chapter also describes the use of aluminium foil as a laminate as well as aluminium metallised films.

**Key words:** aluminium foil, aluminium laminate, aluminium metallised film.

## 9.1 Introduction

Aluminium is a silvery white metal belonging to the boron group of chemical elements and has an atomic number of 13. It has a number of important characteristics:

- It has a third of the density of steel, making it a lightweight metal.
- In alloy form it is strong: whilst pure aluminium has a yield strength of 7–11 MPa, aluminium alloys have yield strengths ranging from 200 to 600 MPa.
- It is resistant to corrosion due to ‘passivation’: the formation of a thin layer of aluminium oxide on the metal surface which prevents further oxidation.
- It is ductile and malleable at normal temperatures, making it easy to form.
- It is non-magnetic but is a good conductor of heat and electricity.

Aluminium is used widely in foil form for packaging at thicknesses of just over 6 to around 150 microns (a micron is one millionth of a metre). The key properties of aluminium as a packaging material are summarised in Table 9.1. One of the most important properties of aluminium as a packaging material is its inertness compared to most metals. As noted earlier, when exposed to air, aluminium forms a transparent oxide layer which prevents further oxidation. As well as being resistant to corrosion, aluminium is non-absorbent and thus an effective barrier against gases and liquid. Heavier gauges of foil (above 17 µm) provide a complete barrier to gases and liquids. Thinner gauges do allow some transmission: as an example, the typical water vapour transmission rate (WTVR) for foil of 9 µm thickness is 0.3 g/m<sup>2</sup> per 24 hours (at a temperature of 38°C and a relative humidity of 90% RH). Aluminium is also stable in cold conditions and can be used for frozen food. It is resistant to temperatures below 150°C, making it suitable, for example, for the storage and heating of chilled foods.

Aluminium does not generate toxic residues or react with most chemicals, including the majority of foods and beverages. It produces a metal with a smooth surface that is easy to clean. Aluminium does not generate sparks, making it suitable for storage of flammable and volatile materials. Its conductivity makes it useful for such applications as electrostatic shielding and induction heat sealing for packaging

Table 9.1 Key properties of aluminium as a packaging material

Property	Advantages
Appearance	Bright, reflective gloss makes for an attractive appearance
Stability	When exposed to air, aluminium forms an oxide layer that prevents further oxidation. It is also inert and does not form toxic compounds when exposed to most chemicals, including most foods and cosmetics
Barrier properties	Heavier gauges form a complete barrier to gases and water. Aluminium reflects light, making it a suitable material to protect light-sensitive products
Hygienic properties	Aluminium's smooth metallic surface is non-absorbent. It can be easily cleaned and sterilised
Formability	Aluminium's ductility makes it easy to form. It has excellent dead-fold properties. Its friability (ability to crumple) makes it useful for blister packaging
Conductivity	Aluminium conducts electricity and heat, making it useful for applications such as induction heat sealing of containers
Recyclability	Aluminium can be recycled at relatively low cost (recycling requires about 5% of the energy required to refine aluminium)

closures (see Chapter 15). Its reflectivity means that it can be used to protect light-sensitive products.

As well as these functional properties for packaging, aluminium also has a smooth, bright and reflective appearance which gives it a decorative value. In foil form, the ductility of aluminium means that it can easily be moulded into a variety of container shapes as well as be processed into foil. It also means aluminium has excellent dead-fold properties, i.e. once folded it retains the shape of the fold. Another increasingly important advantage is aluminium's recyclability. Aluminium and its alloys can be recycled at about 5% of the energy consumption required to refine the original ore. Aluminium can easily be separated from other metals for recycling as it is non-magnetic.

Aluminium does have a number of disadvantages. Pure aluminium loses significant strength at temperatures above 150°C which means a protective coating is needed if it is to be exposed to further heat processing, e.g. cooking. Whilst useful for formability, the ductility of aluminium means that aluminium foil is easily torn or punctured. A particular problem is flex cracking, i.e. the tendency of foil to split when folded or stretched. At gauges below 17 µm, the foil can also suffer from 'pinholes', minute holes caused by impurities in the metal or process variations. Pinholing allows water and gas to penetrate the metal. A protective coating or incorporation of the foil as part of a laminate (composite layer) may therefore need to be added to increase strength, prevent flex cracking and counteract pinholing. Coating and lamination are discussed in Section 9.6.

These weaknesses in aluminium foil can be an advantage in some packaging applications, for example in the production of blister packs for tablets, where the foil needs to break easily to allow access to the product. It is also important to be aware that aluminium foil is not resistant to all chemicals. Whilst the fats or mild

organic acids generally found in food have little or no effect on aluminium, strong mineral acids will corrode bare foil. Mildly alkaline components (e.g. soaps and detergents) may also have a corrosive effect. Salt and other caustic agents will also corrode aluminium. In these conditions, a coating or lacquer is required to protect the metal.

## 9.2 Aluminium processing

Aluminium is the most abundant metal found in the Earth's crust (approximately 8%) and is the third most abundant element found on Earth, after oxygen and silicon. Due to its reactive behaviour, aluminium is never found as a pure metal in nature but combined with hundreds of minerals. The chief source of commercially manufactured aluminium today is bauxite. Bauxite is a reddish-brown clay-like deposit containing iron, silicates and aluminium oxides, the latter comprising the largest constituents. At present, bauxite is so plentiful that only deposits containing a content of aluminium oxides greater than 45% are selected to manufacture aluminium. Bauxite derives its name from a small French town called Les Baux, where bauxite was first discovered in 1821. Today, the largest bauxite mines are located in North America, the West Indies, Australia and Northern Europe.

Since bauxite occurs naturally at the surface of the Earth's crust, mining practices tend to be straightforward. Surface pits are opened using explosives to reveal bauxite beds. The bauxite ore is then excavated and loaded into trucks or rail cars for transportation to the converting or processing centre. In order to produce commercial-grade aluminium from bauxite, essentially two processes must be employed:

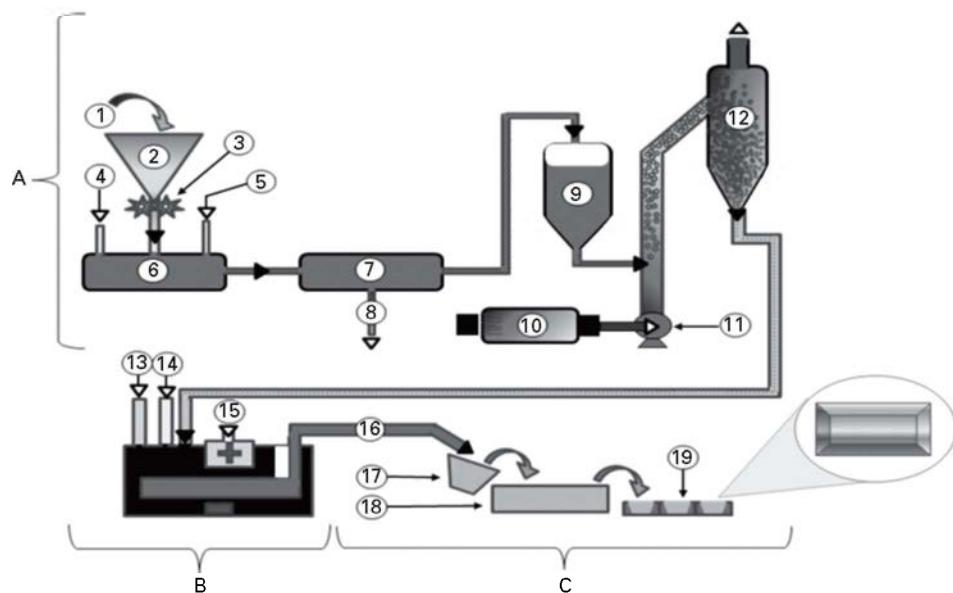
- the bauxite ore must be refined to remove impurities (this is called the refining step).
- aluminium metal is extracted from aluminium oxide using electrolysis (this is the smelting stage).

Following on from these initial steps two further processes are required:

- the aluminium is processed and rolled into foil
- special surface finishes are applied to enhance appearance, decorate, strengthen, protect or provide specialist functions, for example giving foil heat-sealing properties.

A flow process diagram for aluminium manufacture from bauxite is shown in Fig. 9.1.

The processes of refining and smelting require abundant electrical power and for this reason aluminium production is frequently located in areas where cheap electricity is readily available, e.g. northern Scotland and Scandinavia, where hydro-electric power is used. It is estimated that it takes 4 kg of bauxite to produce 2 kg of aluminium oxide, which, with the consumption of about 8 kW of electricity, produces 1 kg of pure aluminium. Due to the high costs associated with aluminium manufacture, metallurgists are continually investigating new approaches to the extraction of aluminium from bauxite in an attempt to reduce overall cost and environmental impact.



9.1 Illustration of the aluminium manufacturing process encompassing the chemical extraction process (A), electrolysis (B) and alloy casting (C) operations (1. Raw material (bauxite) is processed into pure aluminium oxide (alumina) prior to its conversion to aluminium via electrolysis. This primary step is achieved through the 'Bayer Chemical Process'. Four tonnes of bauxite are usually required in order to generate two tonnes of finished alumina which ultimately produces approximately one tonne of aluminium at the primary smelter. 2. Bauxite feed hopper. 3. Mechanical crusher employed to reduce bauxite particle size and increase surface area for chemical extraction. 4. Input chemical (sodium hydroxide). 5. Input chemical (lime). 6. Aluminium oxide is effectively released from bauxite in the presence of caustic soda solution within the primary reactor (digestion) tank. 7. The aluminium hydroxide is then precipitated from the soda solution. 8. Spent solids/tailings discard a red mud residue generated as a byproduct of the process. 9. Precipitation tank: aluminium hydroxide is precipitated from the soda solution. The soda solution is recovered and recycled within the process. 10. Drying system (air heater system). 11. Drying system (hot air blower system). 12. Drying system (cyclone fines recovery system): post calcination, the anhydrous end-product, aluminium oxide ( $\text{Al}_2\text{O}_3$ ), is a fine grained free flowing, white powder. 13. Input chemical (aluminium fluoride –  $\text{AlF}_3$ ). 14. Input chemical (cryolite –  $\text{Na}_2\text{AlF}_6$ ). 15. Fuel source (e.g. coke, petroleum and pitch). 16. Molten aluminium: the reduction of alumina into liquid aluminium is operated at around  $950^\circ\text{C}$  in a fluorinated bath under high intensity electrical current. This electrolytic process (A) takes place in cells or 'pots', where carbon cathodes form the bottom of the pot and act as the negative electrode. Positive electrodes (anodes) are held at the top of the pot and are consumed during the process when they react with the oxygen generated from the alumina. Two types of industrial anodes are currently in use. All potlines built since the early 1970s use the pre-bake anode technology where anodes manufactured from a mixture of petroleum coke and coal tar pitch (acting as a binder) are pre-baked in separate anode plants. In the Soderberg technology, the carbonaceous mixture is fed directly into the top part of the pot, where self-baking anodes are produced using the heat released by

Continued

### 9.3 Refining

The refining step, which is also known as the Bayer process, is carried out in four stages:

- digestion
- clarification
- precipitation
- calcination.

In the digestion stage, ground bauxite is generally mixed with sodium hydroxide and pumped to heated and pressurised digestion tanks where the ore breaks down to soluble sodium aluminate and insoluble components which settle out in the tank. The clarification stage then follows. This entails passing the sodium aluminate through a series of filtered presses which are connected to tanks. The textile-based filters remove contaminants from the solution. This process can be repeated a number of times, depending on the level of contaminants present in the sodium aluminate solution. Finally this solution is then forwarded to cooling towers. From here, the aluminium oxide (alumina) is transferred to a large agitated tank or silo where the aluminium oxide fluid is seeded with hydrated aluminium crystals, thereby promoting the formation of aluminium particles. As the aluminium particles form, the hydrated and seeded aluminium crystals are attracted to each other and entrap the aluminium particles. This causes agglomeration to occur which causes clumping. As clumping develops, large agglomerates of aluminium hydrate form. As this stage in the process suggests, precipitation of aluminium hydrate occurs. The material is filtered and washed. The final stage in the refining process is calcination. This occurs when the aluminium hydrate is exposed to high temperatures in rotary kilns which drive off water and produce a white powdered material called aluminium oxide, or pure alumina, which resembles granulated sugar in appearance.

### 9.4 Smelting

The smelting step is employed to process the alumina. Its primary function is to separate alumina into metallic aluminium and oxygen by means of electrolysis, a procedure that was originally devised by Charles Hall and Paul-Louis-Toussaint Héroult in the late nineteenth century. The modified electrolytic method used today requires that the alumina is firstly dissolved in what is described as a smelting cell.

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*Continued caption fig. 9.1*

the electrolytic process. 17. At regular intervals, molten aluminium tapped from the pots is transported to the cast house crucible. 18. The aluminium is alloyed in holding furnaces by the addition of other metals (according to end user needs), cleaned of oxides and gases. 19. The liquid metal is then cast into ingots. These can take the form of extrusion billets, for extruded products, or rolling ingots, for rolled products, depending on the way it is to be further processed. Aluminium mould castings are produced by foundries which use this technique to manufacture shaped components.)

A smelting cell is made from steel, lined with carbon and filled with heated cryolite. Cryolite is an aluminium-based compound that has strong conductive properties. Once the smelting cell is filled with cryolite, an electric current is passed through the cryolite and this causes a surface crust to form on the alumina. This crust is not a permanent feature and is broken regularly through further alumina additions and via stirring. As the alumina decomposes during this electrolytic process, pure molten aluminium metal falls out of solution to the bottom of the smelting cell. The oxygen gas generated as part of this process combines with the carbon lining in the cell to produce carbon dioxide.

The purified molten aluminium is now collected from the bottom of the smelting cell by siphoning it off into crucibles which are then emptied into furnaces. At this point other elements may be added to the aluminium. The addition of other elements is dependent on the characteristics required from the aluminium alloy in question. Elements added include copper, zinc, magnesium, manganese and/or chromium. Aluminium alloys containing small amounts of these elements have excellent strength properties. As an example, Alloy 3003, which contains manganese, has greater stiffness as well as improved processing properties for cans or containers for pastries and pies. Alloys 1100, 1145 and 1235 are most commonly used for reroll stock for foil. Alloy 1200 is commonly used for packaging applications. Aluminium foils are made in several tempers (i.e. degrees of hardness), dependent on their application. As an example, blister packs require the foil to be in a half-hard temper so that the foil can be easily punctured for ease of access to the product.

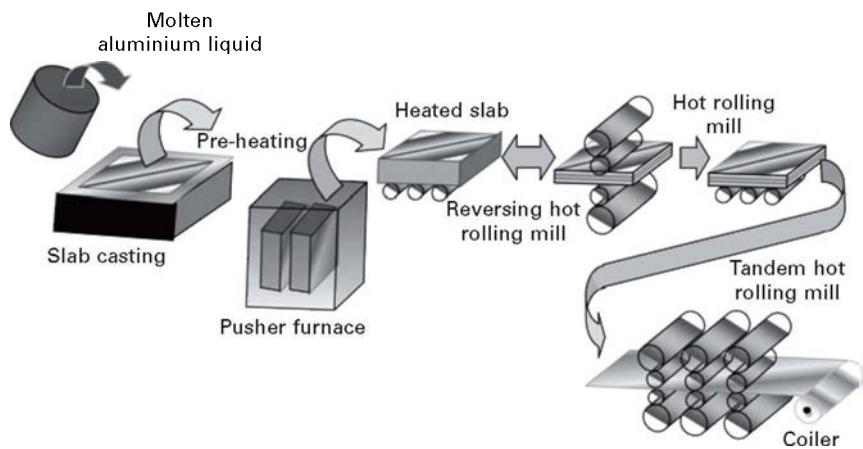
The modified molten aluminium is then poured into chilled casting moulds where it cools and sets to form large aluminium blocks or slabs called 'rolling ingots' which typically range in weight between 10 and 25 tons. These 'rolling ingots' are reduced to 'reroll stock' or sheets approximately 3–6 mm thick. All reroll stock is supplied to aluminium foil manufacturers in 0 temper (i.e., in its softest form) so that it can be worked easily.

## 9.5 Production of aluminium foil

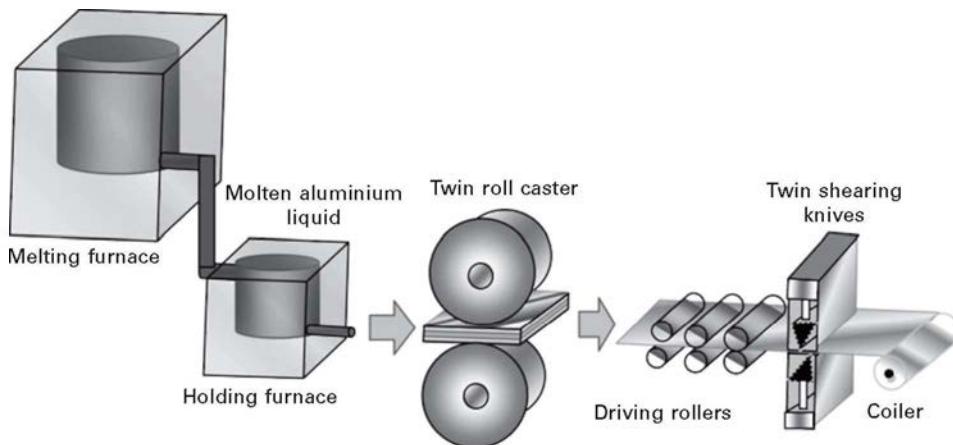
Aluminium foil is typically less than 150  $\mu\text{m}$  in thickness. Foils are available in gauges as low as 6.3  $\mu\text{m}$ . Heavier foil gauges ( $> 17 \mu\text{m}$ ) provide an absolute barrier to gases and liquids. A typical water vapour transmission rate (WVTR) for 9  $\mu\text{m}$  foil is 0.3  $\text{g}/\text{m}^2$  per 24 hours at 38°C and 90% RH. As thickness is reduced, foil becomes more vulnerable to tearing or pinholing. Aluminium foil is produced by two basic processes:

- the traditional method of rolling aluminium slabs, ingots or thick plates into a narrow gauge aluminium web stock using heavy rolling mills (Fig. 9.2),
- by continuous casting or hot-strip casting (similar to an extrusion process) which takes place immediately after the aluminium has left the furnace (Fig. 9.3).

Because it has been established for longer, the rolling-mill method of producing reroll stock is still widely used. When being rolled to foil, ingot-rolled stock must be re-annealed (reheated) between mill passes to overcome work hardening and restore



9.2 The conventional rolling-mill method of producing reroll aluminium stock and ultimately, aluminium foil.



9.3 Continuous casting or 'hot-strip' casting to produce aluminium reroll stock and ultimately, aluminium foil.

workability. The most economical means of manufacturing reroll stock, however, is via continuous casting. A typical continuous-casting production line runs directly from the furnace to a winding reel. The system continuously feeds, casts, chills and coils the reroll stock. Since it is heated during production, continuous-cast reroll stock does not need to be re-annealed when being made into foil.

After the foil stock has been manufactured, it must be further processed on a rolling mill. The work rolls have finely ground and polished surfaces to ensure a flat, even foil with a bright finish. The work rolls are paired with heavier backup rolls which exert very high pressure on the work rolls to ensure stability. This pressure ensures a uniform gauge (thickness) across the resulting aluminium foil sheet (known as a web). Each time the foil stock passes through the rolling mill, it is squeezed, its thickness is reduced and its length increases, but its width remains the same. This

means the required width for the final foil product must be set at the beginning of the process.

The rolling process can be viewed as a form of extrusion. Foil gauges under 25  $\mu\text{m}$  are often passed through the work rolls in two webs at a time. This is done so that the two webs of foil support each other and are less likely to tear when rolled. During the rolling process, the aluminium stock requires annealing to maintain workability. The addition of lubricants to the aluminium surfaces also maintains the workability of the material. A final annealing stage removes the lubricating oil, thus making the foil receptive to printing inks and adhesives.

## 9.6 Foil finishes, coatings and lacquers

Rolling produces two natural finishes on foil: bright and matte. The foil surfaces in contact with the work rolls are polished to a bright and shiny finish. When a single web is run, both sides are bright. If thinner foils are rolled together, the foil-to-foil face of each web develops a satin-like matte finish. Other finishes can be produced with special patterns on the work rolls or, more commonly, by using separate or in-line mechanical finishing machines (Table 9.2).

In most packaging applications, aluminium foil is combined with other materials such as coatings, inks, papers, paperboards and plastic films. A very useful characteristic of aluminium foil is that it has the capacity to readily accept many different types of coating materials such as inks (for printing), varnishes and lacquers (for embossing), adhesives and polymers (for heat sealing, etc.). The selection of foil alloys, gauges and tempers needs to take into account the type of coating or lacquer required.

Where a coating is needed, gravure coating is used for most low-viscosity materials. Heavier coatings require some form of roll coater. Coatings generally can be classified as protective or decorative. Protective functions for coatings include:

- making the foil more heat-resistant
- increasing tensile strength
- increasing resistance to potentially corrosive agents
- enhancing the barrier properties of low gauge foil
- increasing resistance to scratching or scuffing
- increasing the UV resistance of a printed foil.

*Table 9.2 Standard aluminium foil finishes and treatments used in packaging*

Type of finish	Description
Bright both sides	Uniform bright specular finish, both sides
Extra-bright both sides	Uniform extra-bright specular finish, both sides
Matte one side	Diffuse reflecting finish, one side
Matte both sides	Diffuse reflecting finish, both sides
Embossed	Pattern impressed by engraved roll or plate
Annealed	Completely softened by thermal treatment
Chemically cleaned	Chemically washed to remove lubricants
Hard	Foil fully work-hardened by rolling
Intermediate temper	Foil temper between annealed and hard

Vinyl heat-seal coatings are widely used with aluminium foil. It is important that the coating is compatible with the product. It is also important to note that a normal heat-seal coating does not add significantly to a foil's bursting strength. Coatings are only likely to add to foil strength above thicknesses of 25 µm. Table 9.3 lists the chemical resistance of some coating materials. Table 9.4 lists the general properties of the various coatings applied to foil.

Decorative and other functions include giving additional gloss and depth to a decorated or printed foil, or improving the adhesive quality of the foil for other

Table 9.3 Chemical resistance of coating materials

Coating type	Acid	Alkali	Water	Solvent
Acrylics	Fair	Fair	Fair	Good
Alkyd	Fair	Fair	Good	Good
Butadiene-styrene	Excellent	Excellent	Excellent	Good
Butyrate	Fair	Fair	Fair	Fair
Cellulose acetate	Fair	Fair	Fair	Fair
Chlorinated rubber	Excellent	Excellent	Excellent	Fair
Epoxies	Excellent	Excellent	Excellent	Excellent
Ethyl cellulose	Fair	Excellent	Good	Fair
Melamine	Excellent	Excellent	Good	Good
Nitrocellulose	Good	Fair	Excellent	Good
Polyamide-epoxy	Fair	Excellent	Excellent	Good
Polyester	Good	Fair	Good	Good
Polystyrene	Excellent	Excellent	Excellent	Fair
Polyvinyl acetate	Fair	Fair	Good	Poor
Polyvinylidene chloride	Excellent	Excellent	Excellent	Fair
PVAC chloride copolymer	Excellent	Excellent	Excellent	Fair
Styrenated alkyd	Fair	Good	Good	Fair
Urea	Excellent	Excellent	Excellent	Good

Source: Aluminium Association, *Aluminium Standards and Data*.

Table 9.4 General properties and characteristics of typical aluminium foil coating compounds

Quality	Celluloses					
	Ethyl	Nitro	Alkyds	Phenolic	Polyester	Epoxy Vinyls
Abrasion resistance	1	1	2	1	2	2
Block resistance	3	1	2	1	1	3
Heat sealability	1	2	3	3	2	1
Water resistance	3	2	2	1	1	1
Alkali resistance	1	3	3	1	1	2
Fat and oil resistance	3	2	2	1	1	1
Colour stability	2	3	2	1	1	1
Film gloss	2	2	1	1	1	3
Transparency	2	2	3	1	1	1

The quality rating score equates to: 1 = best performance, 2 = satisfactory performance or frequently used and 3 = unsatisfactory performance.

coatings or printing inks. The use of transparent lacquers and varnishes gives foil a particularly bright metallic sheen. Coloured lacquers help to impart colour; for example, yellow gives aluminium a gold appearance.

### 9.7 Printing and embossing

If foil is to be printed, it is important to be aware that its glossy surface may make small print difficult to read. Reverse type is best avoided, unless it is large. It is sometimes necessary to print a matt white background on which black type will be more visible. Printers usually print foil on the same presses used for paper or other material. If a foil is to be printed, it is given a primer or wash coat to ensure a clean surface and to provide a foundation for the ink. Shellacs and vinyls are common primers for gravure and flexographic printing. If a thicker coating is required, e.g. for lithographic printing, vinyl copolymer or nitrocellulose may be used. A second film coat may then be applied on top of the printing to protect it from scuffing as well as to reduce surface friction.

Aluminium foil is particularly suited to embossing. This gives both a three-dimensional quality to a design and increases the number of reflective surfaces able to reflect light to create a more eye-catching effect. It also increases stiffness (see below) and allows cut pieces of foil to be easily separated, e.g. stacks of pre-cut lids. Thinner gauge foil in web (sheet) form is passed between a steel roll containing the engraving pattern and a soft matrix roll (usually paper). Heavier-gauge, coated or laminated foil is embossed with two engraved steel rolls, one with the positive image, the other the negative image. Since it requires further processing with rollers, embossing tends to improve foil stiffness and dead-fold properties.

### 9.8 Using aluminium foil as a laminate

Lamination involves combining sheets of different materials into a single layer, using a mixture of adhesives, pressure and sometimes temperature to bond the materials together (see also Chapter 14). Aluminium foil is laminated on web-fed rotary equipment which sometimes includes a coating unit to add further protection. Adhesives are selected on the basis of their suitability for the materials to be joined as well as such issues as any toxicity or contamination risk they might present, potential odour or colour issues, moisture and heat resistance. The main types of adhesives used are:

- heat-sealable adhesives
- water-soluble emulsions and dispersions
- thermoplastics in lacquer-type solvents
- hot melts (natural or synthetic waxes)
- extruded-film adhesives.

Four methods are used to laminate aluminium foil:

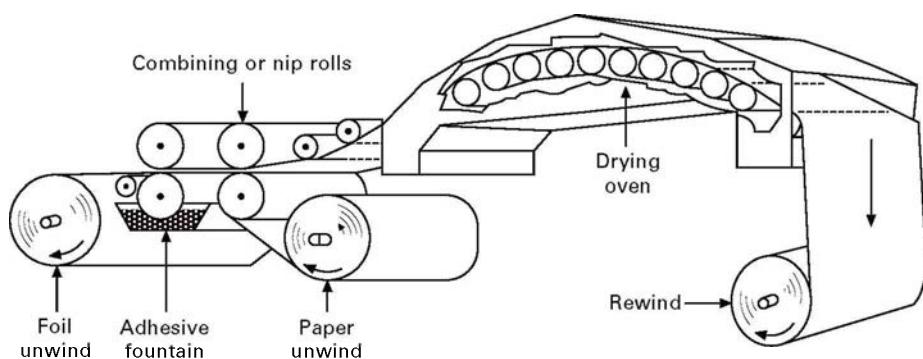
- wet bonding
- dry bonding

- extrusion bonding
- hot-melt bonding.

As the name suggests, wet bonding involves combining the various layers before the adhesive is dry. A water- or solvent-based adhesive is used and is normally applied to the foil. Further layers are then applied on top and the laminate passed through a combining or nip roll at varying drying temperatures, depending on requirements (Fig. 9.4). Materials laminated to the foil base need to be porous so that the liquid medium of the adhesive can be taken up and the adhesive properly dried, thus paper is an ideal material for wet bonding. The smoother, denser and less porous the paper, the less adhesive is required. A low paper moisture content is important to ensure good adhesion and prevent problems such as staining. It is important to combine and glue the materials quickly to ensure good adhesion and prevent materials slipping as they are fed through the machine. The use of a rapidly setting adhesive also helps to minimise the risk of air pockets or blisters in the laminate, particularly if the laminate is stressed or flexed in subsequent processing, e.g. coating operations. High drying temperatures improve bonding and water resistance, but they can over-dry and damage papers or boards.

Where materials are not porous, dry bonding is used instead of wet bonding. Dry-bond adhesives use both natural and synthetic sealing agents and can be either water or organic solvent based (see Chapter 16). Synthetic agents include vinyls, epoxies, polyesters and urethanes. The adhesive is applied to the foil and allowed to dry. The layers are then aligned and passed through a heated combiner roll which reactivates the adhesive to create the bond. This method is well suited to non-porous materials such as polyester films, which add strength and flexibility when combined with aluminium foil.

Extrusion bonding involves extrusion of one or two molten plastic films which are then combined with the aluminium foil. As the aluminium foil web approaches the combiner roll, an extruder die deposits a layer of hot extrudate across the width of the web. The laminate then passes through the chilled nip of the combiner roll, cooling the plastic layer which solidifies. No drying is required. When only the two layers are involved, the process is known as extrusion coating.



9.4 Wet-bonding foil lamination process.

The hot-melt process is used for high-speed lamination since there is no need for a drying stage. Hot melts include polymer resins, waxes and resin-wax combinations. The hot-melt can be melted at a lower temperature than extruded coatings, applied to the web and chill-set in the nip of the combiner roll. The plastic nature of the hot melt improves heat-sealability and the dead-fold characteristics of the foil.

Foil laminates intended for barrier applications should be evaluated for their barrier properties using the finished pack after all of the machining is complete, and preferably after a real or simulated shipping cycle. It is not uncommon for a prospective barrier laminate to have no measurable permeability when flat (i.e. at the point of manufacture) but to have significant permeability when formed, folded and creased into a final pack format.

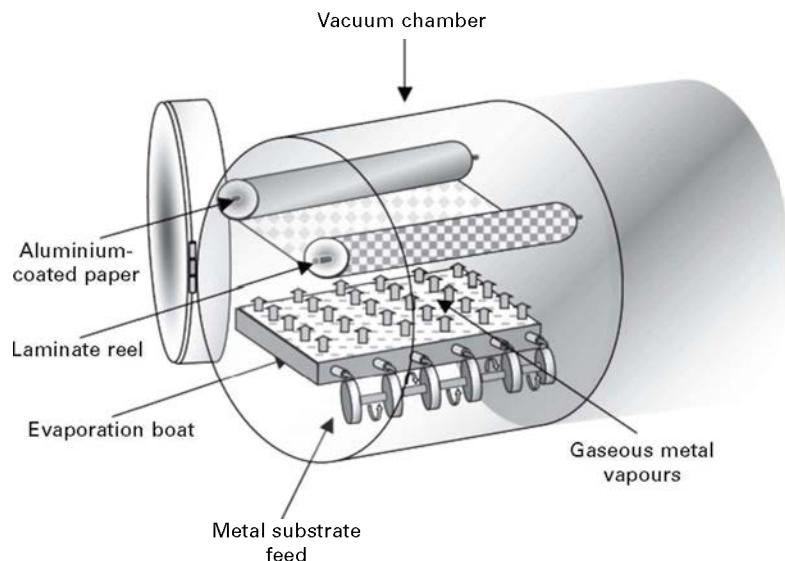
### 9.9 Aluminium metallised films

Vacuum metallising or metallisation involves depositing a metal layer onto a substrate (e.g. paper or plastic film) in vacuum conditions. Aluminium is the only metal used for vacuum metallising in packaging applications. Initially used for decoration, metallisation is now widely used in flexible packaging since it improves gas and moisture barrier properties, heat resistance, light reflectance and electrical conductivity. Crisp packets, for example, are typically made of metallised polypropylene which provides effective protection for the required shelf life of this type of product. Metallised films are often a component in a laminate. Table 9.5 lists examples of laminates that use metallised films. Since aluminium is effective in converting microwave energy to heat, metallising is also used in 'susceptor' packaging of microwavable foods where the metallised component serves to create a local microwave energy 'hot spot'. Given the high temperatures involved, the aluminium needs to be protected by a heat-resistant layer, for example of polyester.

Batch processing is the most widely used approach to metallising. It involves a horizontal tubular chamber, up to 2 m in diameter and 3 m long (Fig. 9.5). A series of rollers carry the substrate through the chamber from which the air has been evacuated by vacuum pumps. Pure aluminium wire is fed into containers ('boats') which are electrically heated to vapourise the aluminium. (The vacuum reduces the vapourisation temperature of the aluminium.) As the vapour rises, it condenses on the underside of the substrate as it passes over a chilled drum. The thickness of the metal deposited is controlled by a combination of web speed, wire feed rate and boat

Table 9.5 Typical examples of laminates using metallised films

Product	Type of laminate
Coffee	12 µm metallised BOP/50 µm LDPE
Savoury snacks	18 µm OPP/adhesive/18 µm metallised OPP
Condiments/spices	12 µm metallised PET/38 µm MDPE
Bag-in-box wine	50 µm ionomer/12 µm metallised PET/75 µm EVA
Biscuits	OPP/18 µm metallised OPP
Medical products	paper/adhesive/18 µm metallised OPP/ionomer
Cold meats	metallised PET/PE



9.5 Vacuum metallising is a form of physical vapour deposition, a process of combining metal with a non-metallic substrate through evaporation. The most common metal used in vacuum metallisation is aluminium for a variety of reasons including cost, thermodynamic and reflective properties. The evaporation takes place by feeding aluminium onto heated sources or boats, which operate at approximately 1,500°C (2,700°F). The atmosphere in the vacuum metallising chamber is evacuated to a vacuum level suitable for the evaporation of the aluminium wire. Upon contact with the substrate being processed, the aluminium vapour condenses and creates a uniform layer of vacuum deposited aluminium.

temperature. A batch can handle reels of up to 20,000 m long in just under an hour. The thickness of the aluminium layer is as low as three-millionths of a centimetre. Electrical resistance and optical density are the two main methods for testing deposition and layer thickness. Metallised patterns can be achieved by metallising a pre-printed film, or using caustic solutions to selectively remove the metallic layer to create patterns or windows in the metallised film.

Metallised papers need to be high-quality virgin stock usually with a clay coating to provide a smooth surface and high reflection in the finished metallised surface. Papers also need to be lacquer coated using gravure coaters to seal the paper and ensure a good, even metal adhesion. The lacquer is dried using radiant heating, UV, electron beam or infrared curing. Developments in paper quality and lacquer technology have significantly expanded the use of metallised papers in areas such as labels and cartons for cosmetics. Since the vacuum and temperature conditions reduce the moisture content of paper substrates to below 5%, remoistening is an essential step in the manufacture of metallised paper to avoid curling. Although most plastic films can be metallised, oriented polypropylene (OPP), biaxially oriented polypropylene (BOPP), polyethylene terephthalate (PET) and biaxially oriented nylon (BON) are

the most commonly metallised packaging films. Unlike paper, plastic films do not need to be sealed to be metallised.

## 9.10 Conclusion

Because of the numerous beneficial characteristics of the metal, the way it can be converted to foil, used in laminates or to metallise films, aluminium use is widespread throughout the packaging industry, particularly with respect to fast-moving consumer products. The numerous packaging formats and the products that it is associated with are presented in Table 9.6. Examples of container types are shown in Fig. 9.6.

## 9.11 Acknowledgements

I gratefully acknowledge the assistance of Mr Eddie Beatty and Mr Dave Waldron in the preparation of the photographic material presented in this chapter and to Dr John F. Kerry, Echo Ovens International Ltd, Raheen, Limerick, Co. Limerick for his assistance with the preparation of figure material for this chapter. All ownership of such material resides with The Food Packaging Group in University College Cork and with Echo Ovens International Ltd.

Table 9.6 End uses for aluminium foil as packaging material

Packaging format	Products
Rigid smooth wall containers	Meat joints for roasting, large portioned ready-meals and convenience-style food products (Fig. 9.6)
Semi-rigid wrinkle wall containers	Take-away meals, savory pies, bakery products, frozen and chilled ready-meals (Fig. 9.6)
Closure systems	Milk, beverages, instant coffee, dried powders, health foods and pharmaceutical products, cosmetic creams
Labels	Used widely from foodstuff to beverage packaging
Composite cans	Powdered drinks, snack foods, juice-based beverages, instant biscuit/cookie dough, chilled and frozen foods
Flexible packaging	Dairy products: milk, cheese, butter and ice cream Beverages: wines, juices, soft drinks, liquors, beer; non-beverage products: soaps, shampoos, conditioners, detergents, cosmetics Dessicated and powdered products: coffee, tea, cocoa powder, custard, fruit, concentrates, vegetables, dehydrated powders, soups, herbs and spices, yeast and other powdered extracts, salt, sugar, pharmaceuticals, tobacco products Cereal and baking foodstuffs: cake mixes, cereals, frosting mixes, pasta-based products, rice-based products, biscuits, crackers, snack foods, breads Confectionery: chocolate, hard and soft sweets, all products containing volatiles contributing to flavours such as mint, orange, coffee, aniseed, clove, etc. Muscle-based foods: meat, poultry, fish, game, casseroles, stews, soups and broths, general muscle-based retorted products, chilled and frozen products, pet foods



9.6. Examples of a smooth wall heavy gauge deep drawn aluminium container (above) and a wrinkle wall narrow gauge shallow drawn aluminium container (below).

## 9.12 Sources of further information and advice

Most general textbooks on aluminium discuss the metallurgical properties of the metal and its applications as a sheet or extruded material in construction, aerospace and automotive applications, and are thus of limited interest in the context of this textbook.

The following organisations provide useful information specific to aluminium foil in packaging:

- Aluminium Foil Container Manufacturers Association: <http://www.afcma.org>
- Aluminium Federation: [http://www.alfed.org.uk/downloads/documents/D53ZC9P4LP\\_15\\_aluminium\\_packaging.pdf](http://www.alfed.org.uk/downloads/documents/D53ZC9P4LP_15_aluminium_packaging.pdf)
- European Aluminium Association: <http://www.alueurope.eu/wp-content/uploads/2011/10/Aluminium-in-packaging-brochure.pdf>
- European Aluminium Foil Association: <http://www.alufoil.org>
- Australian Aluminium Council: <http://aluminium.org.au/packaging>
- The Packaging Federation: <http://www.packagingfedn.co.uk>
- Aluminium in Packaging: <http://packaging.world-aluminium.org>

# 10

## Paper and paperboard packaging

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**Abstract:** Paper and paperboard are made from cellulose fibres, extracted from trees, combined together with additives to make a continuous matted web. This chapter covers the raw materials, processes and on- and off-line treatments used to manufacture fibrous substrates (paper and paperboard) used for the conversion into packaging components. These components include wrapping materials, bags, sacks, cartons, tubs, lids, moulded fibre packaging, and backing cards for various plastic, paper and paperboard combinations. This chapter will also discuss the different substrates, conversion methods and decorating methods.

**Key words:** paper, paperboard, carton, sack, bag, fibre moulding.

### 10.1 Introduction

'Paper' and 'paperboard' can be described as a matted or felted sheet, usually composed of plant fibre (commonly from trees or recycled paper or paperboard waste, e.g., corrugated cases, newsprint, sacks, bags and cartons). It can also be made from other fibrous materials such as linen, sugar cane, cotton and the stalks of cereal plants such as corn (commonly known as straw) (see Fig. 10.1). The terms 'paper' and 'paperboard' generally refer to the packaging they are used to make. For example, you would refer to the material to make a carton as paperboard and the material to make a corrugated case or paper sack as paper. However, this can be confusing as there is a large range of weights and thicknesses used to make a wide diversity of fibre-based packaging.

As a result of this confusion, the International Standards Organisation (ISO) decided to separate the two. 'Paper' is defined by the ISO as that substrate, made from vegetable fibres, which has a grammage (basis weight) of less than 250 grams per square metre (gsm); 'paperboard' (also known as 'cartonboard', 'cardboard', 'boxboard' or just 'board') has a grammage of 250 gsm or over. This definitive difference, however, is not widely used within the industry, different countries using varying terminology. In the United Kingdom, for example, we use the word 'card' when referring to that particular paper used to make greetings cards and we use the term 'cardboard' when referring generally to stiff paper/paperboard materials, such as corrugated or heavyweight solid paperboard.

Paper and paperboard are the most common packaging raw materials. Paper is used mainly in corrugated board manufacture, spiral tube making, and also in laminates, sack and bag manufacture, and wrapping material for such products as ream-wrap for copier paper. Paperboard is used mainly in cartons. There are many forms of paper with a variety of properties. These properties are further utilised with the help



10.1 (a) Matted fibres (mechanical pulp), (b) matted fibres (chemical pulp)  
(courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

of other materials when combined together in laminates. The other materials, apart from clay and chalk (discussed later), used in conjunction with paper are aluminium foil and plastic films. Coating with polymers also enhances the properties of paper. These coatings vary from fluorocarbon (grease resistance) to water-based and film-based barrier coatings (grease, water, water vapour and gas barrier), making the paper base a very versatile material indeed. Paperboard, though not quite as versatile on its own, can benefit from coating and lamination with polymeric materials and aluminium foil and vacuum deposition in the same way as paper.

## 10.2 Properties of paper and paperboard

The properties of paper and paperboard depend upon many factors and can be tailored to meet the specific needs of the packaging industry. Typical factors included in the discussion which follows throughout this chapter are:

- the source of fibre
- the type of fibre
- how the fibre is extracted from the source
- the amount of treatment the fibres are exposed to during the pulping process
- how the fibres are combined together

- how the fibres are converted to paperboard, and the type of 'mill' used (the term given to the machine on which the paper and paperboard are made)
- the number of plies used to make up a paper or paperboard sheet
- what performance additives and process aids are used
- whether or not the paper or paperboard is bleached, coated or combined with other materials.

#### 10.2.1 The main properties of paper and paperboard

Properties of paper and paperboard vary depending on the grade and specification used. The main properties to be considered in packaging applications are as follows:

- stiffness
- printing surface
- absorbency
- burst strength
- tensile strength
- tear resistance and compression strength
- grease resistance.

Excellent stiffness (some tissue papers excepted) and deadfold of all papers and paperboards, especially bleached and unbleached Kraft and sulphite grades, allow very lightweight papers to be used for bags ensuring their creases are sharp and they stand erect on shelf. The downside is that paper keeps its crease when deformed, detracting from its aesthetic appeal. The use of a sandwich of mechanical pulp between chemical pulps (known as folding boxboard – FBB) maximises the stiffness obtainable for a carton and provides good deadfold when creased (see Fig. 10.2).

The density, whiteness, porosity and smoothness of the bleached paper and paperboard, especially sulphite grades, portray a bright high-quality print when

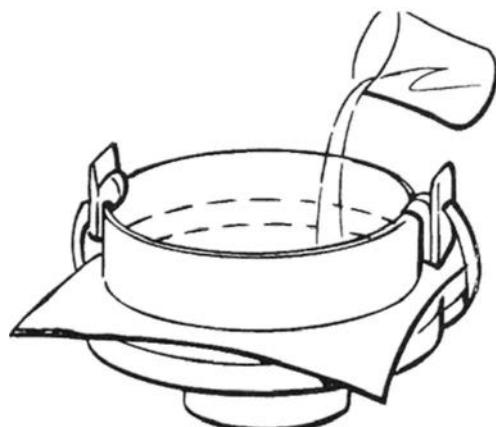


10.2 Paper properties (SBB = solid bleached board; FBB = folding boxboard; WLC = white lined chipboard) (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

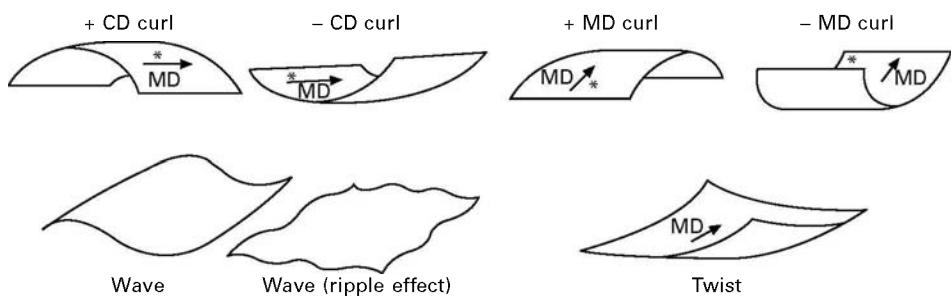
decorated by the offset lithographic, flexographic, gravure or digital processes. (See Chapter 19 for detailed discussion of printing processes.)

The Cobb value (water absorbency) and porosity value of paper and paperboard can be adapted to suit the performance required (see Fig. 10.3). Water-based adhesives ideally require an absorbent surface to dry and set the adhesive by fast removal of water. This allows for efficient adhesion in bag, sack and carton making and labelling. The Cobb value can be adjusted by 'hard sizing' the paper (see later additives for paper and paperboard production) so that the fibres are protected from water, allowing use in frozen and wet environments without significantly reducing the physical properties of the paper. Where absolute water repellency is required, coatings are used, for example plastic film, water-based barrier coatings or silicone coatings.

One of the negative properties of paper and paperboard is that they absorb moisture vapour and water. If one side of the substrate is more absorbent than the other, as with clay-coated or one side polymer-coated material, it will warp. This is a very serious issue if not controlled. It can occur during or after manufacture. It is important, therefore, to control the manufacture to make a stable web and to control the storage to ensure moisture variation is kept to a minimum (see Fig. 10.4).



10.3 Cobb test for water absorbency (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

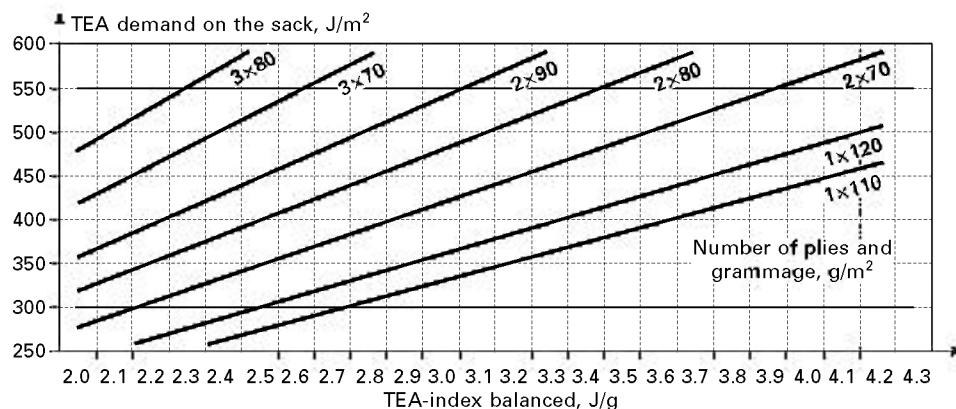


10.4 Warping of paper and paperboard (\* = least absorbent side; + = greatest moisture gain; - = least moisture gain) (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

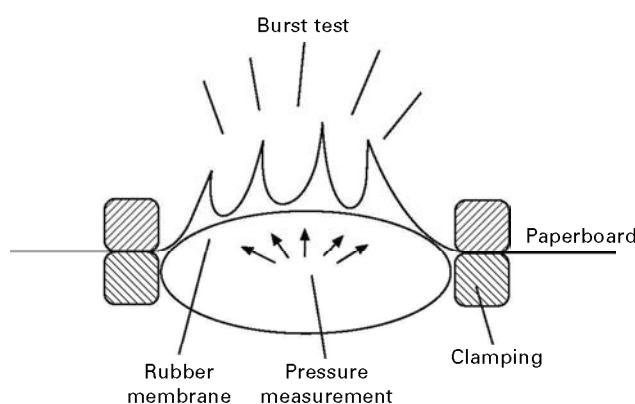
Another property is the burst strength of paper, especially 'sack Kraft'. Paper can be micro-crimped to increase the burst strength and this helps to control and balance the total energy absorption (TEA) and enables it to be used for industrial packaging such as cement sacks and 500 kg flexible intermediate bulk containers (see Fig. 10.5). Once the required total energy absorption levels are known, different combinations of paper plies and weights can be used to achieve it (see Fig. 10.6).

The tensile strength of paper and paperboard is high and their extensibility low, allowing for good constant tension to be applied when printing and laminating papers and during the manufacture of corrugated board, spiral and linear paper tube making and form fill seal (FFS) liquid packaging cartons (see Fig. 10.7).

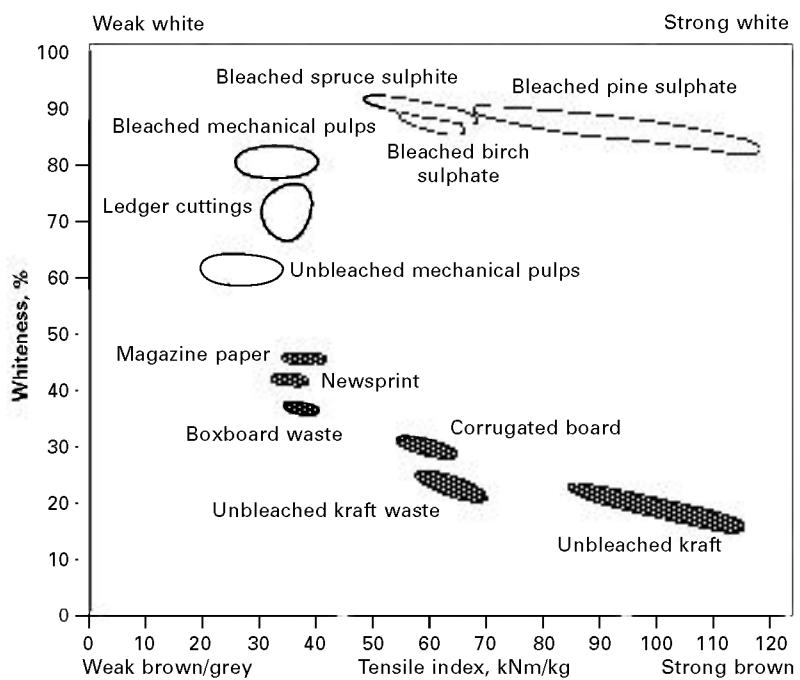
The tear resistance of papers is variable, depending on the type and the manufacturing process, but in general a grade can be selected to meet most packaging uses. The short span compression strength of paper and paperboard can determine the resistance to compression, provided the height and dimensions of the carton footprint are known.



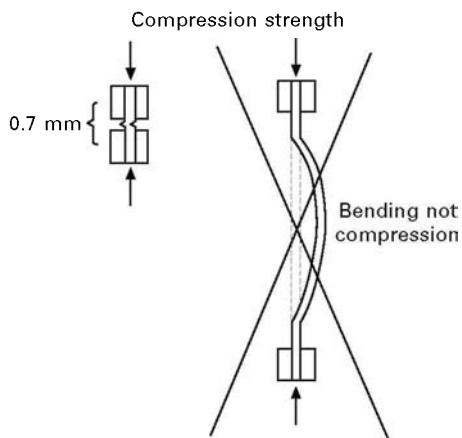
10.5 Total energy absorption (TEA) levels for different combinations of paper plies and weight.



10.6 Principle of burst strength (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



10.7 Difference in whiteness and tensile strength of primary and recycled paper and paperboard grades (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



10.8 Compression strength testing (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

It is important that the distance between the jaws of the test rig is no greater than 0.7 mm, otherwise bending will affect the result (see Fig. 10.8).

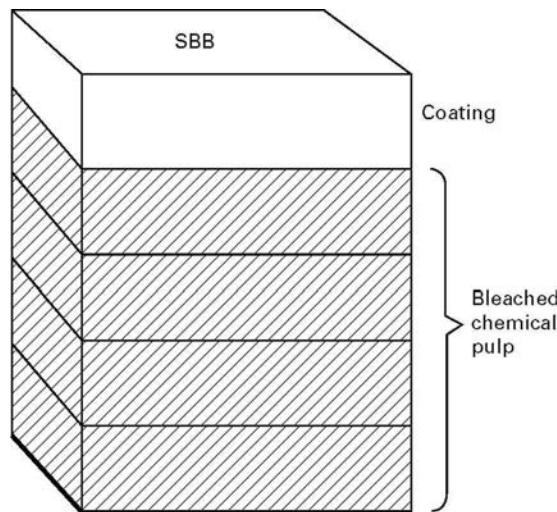
Paper can be made to have varying degrees of grease resistance, either by treating the fibres and paper physically or chemically. Physical treatment of the fibres is

known as beating or refining, to produce grease proof or grease resistant (GP or GR) paper. Chemical fibre treatments include adding fluorocarbon to the furnish or at the size press. GP papers can be further treated by supercalendering to produce a translucent grease resistant paper known as 'glassine'. The ultimate in grease resistance is achieved by dissolving some of the fibres in sulphuric acid to produce parchment, which also has a very low gas permeability.

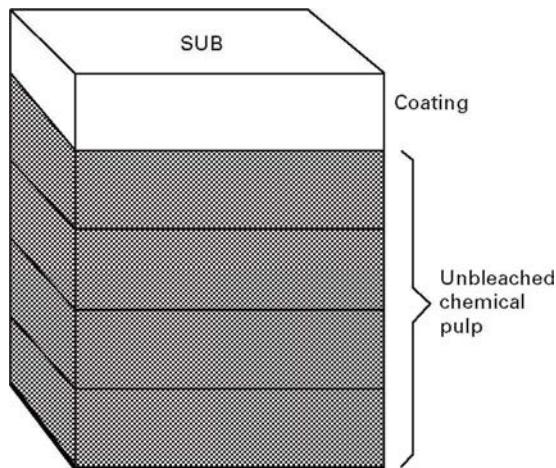
### 10.2.2 Paperboard grades

Grades of paperboard used can be generally classified as follows.

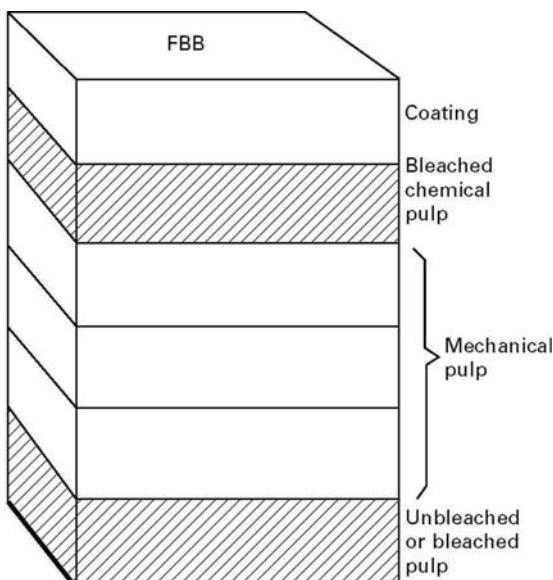
- Solid bleached board (SBB): paperboard made from virgin bleached chemical pulp (Fig. 10.9).
- Solid unbleached board (SUB): paperboard made mainly from unbleached virgin chemical pulp. A layer of bleached fibre is sometimes added to the top to provide greater whiteness (Fig. 10.10).
- Folding boxboard (FBB): made from a layer or layers of mainly virgin mechanical pulp sandwiched between layers of virgin chemical pulp. The top layer is bleached chemical pulp and the bottom layer can be either bleached or unbleached virgin chemical pulp (Fig. 10.11).
- White lined chipboard (WLC): made from multi-layers of recycled fibres. The top layer can be made from bleached virgin chemical pulp or white deinked recycled fibres. Between the top layer and the middle layer(s) there can be a layer of chemical, mechanical or deinked recycled fibres. The bottom layer can be made from selected recycled or bleached and/or unbleached virgin fibres (Fig. 10.12).



10.9 Solid bleached board (SBB).



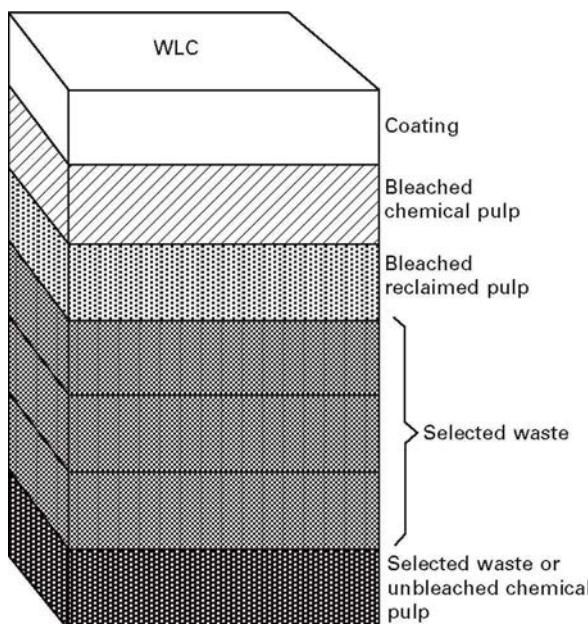
10.10 Solid unbleached board (SUB).



10.11 Folding boxboard (FBB).

There are other boards available which are combinations or variations of the above. Two examples are:

- CCNB – clay coated news back – news back refers to the layer(s) of pulp beneath the coating made specifically from recycled newspapers rather than mixed waste. This creates a very smooth light grey underside but, due to the short fibres, this material can only be used where the physical strength of the carton is relatively unimportant.
- CCKB–clay coated Kraft back (also known as CKB in Europe and coated kraft



10.12 White lined chipboard (WLC).

back or CCCB – clay coated craft back in the United States). Kraft back can refer to virgin sulphate unbleached pulp or fibre recovered from used corrugated cases. This is a much stronger board than CCNB and in some instances can compete with Kraft boards.

The DIN 19303 standard for classification of paperboards is a little more refined than the traditional terminology used in the United States and the United Kingdom, and is now being adopted by most European carton manufacturers (see Table 10.1).

### 10.2.3 Comparison and properties of different types of paper and paperboard

As has already been mentioned, the properties of paper and paperboard vary greatly, depending on grade and specification. At this point it is worth considering some general comparisons of different types of paper and paperboard as shown in Figs 10.13–10.15. Comparisons are made taking account of bleached vs. unbleached materials, and materials made from virgin chemical pulp, virgin mechanical pulp and recycled fibres. These materials and processes are discussed in detail later (Fig. 10.13). It can be seen that bleached chemical pulps are generally weaker than unbleached pulps but both are stronger than mechanical pulps. Also, as expected, bleached pulps are whiter than unbleached pulps (see Fig. 10.14).

Mechanical pulp is stiffer than chemical pulp but not as strong. Fortunately the manufacturer is able to combine pulps for maximum overall performance, for example, folding boxboard (FBB) has inner plies of mechanical pulp and outer plies of chemical pulp. This provides a board with maximum stiffness at minimum grammage. If we

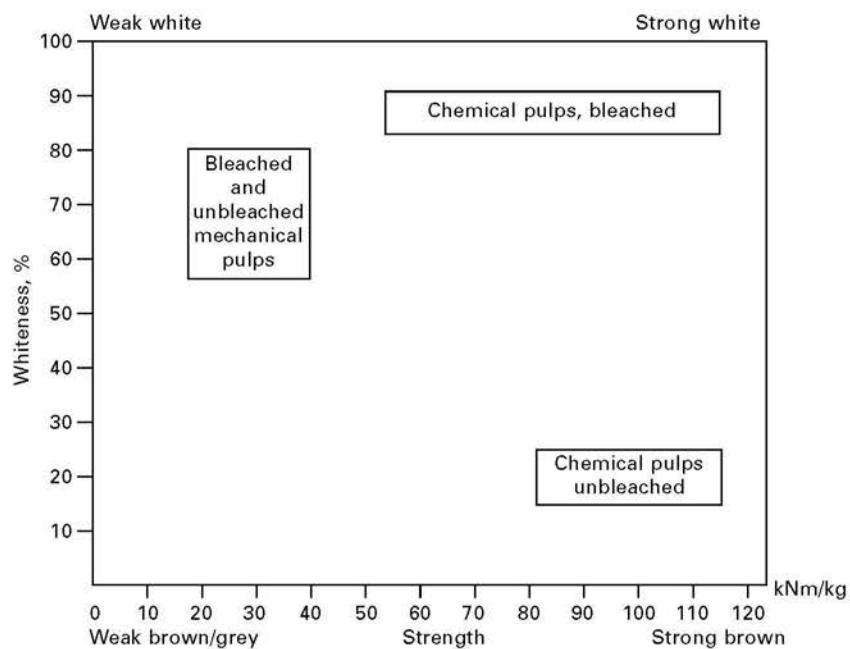
Table 10.1 DIN 19303 European classification for qualities of paperboard

Abbreviations (German terminology)	Description
GZ	Coated SBB
GGZ	Cast coated SBB
GG1	Cast coated FBB white back
GG2	Cast coated FBB manilla back
GC1	Coated FBB white back
GC2	Coated FBB manilla back
GT	Coated CB manilla or white back
GD1	Coated CB high bulk (spec. volumemin 1.5 cm <sup>3</sup> /g)
GD2	Coated CB (spec. volume min 1.4 cm <sup>3</sup> /g)
GD3	Coated CB low bulk (spec. volume min 1.3 cm <sup>3</sup> /g)
GN1	SUB
UZ	Uncoated SBB
UC1	Uncoated FBB white back
UC2	Uncoated FBB manilla back
UT	Uncoated CB manilla or white back
UD1	Uncoated CB top liner woodfree
UD2	Uncoated CB top liner near woodfree
UD3	Uncoated CB top liner partly mechanical pulp
Key:	
SBB	Solid bleached board
SUB	Solid unbleached board
FBB	Folding boxboard
CB	Chipboard (more often WLC = white lined chipboard)
G	Gestrichen, coated
U	Ungestrichen, uncoated
GG	Gussgestrichen, cast coated
Z	Zellulosekarton, solid boxboard
C	Chromoersatzkarton, folding boxboard
D	Duplex (CB construction)
T	Triplex (CB manilla or white back construction)

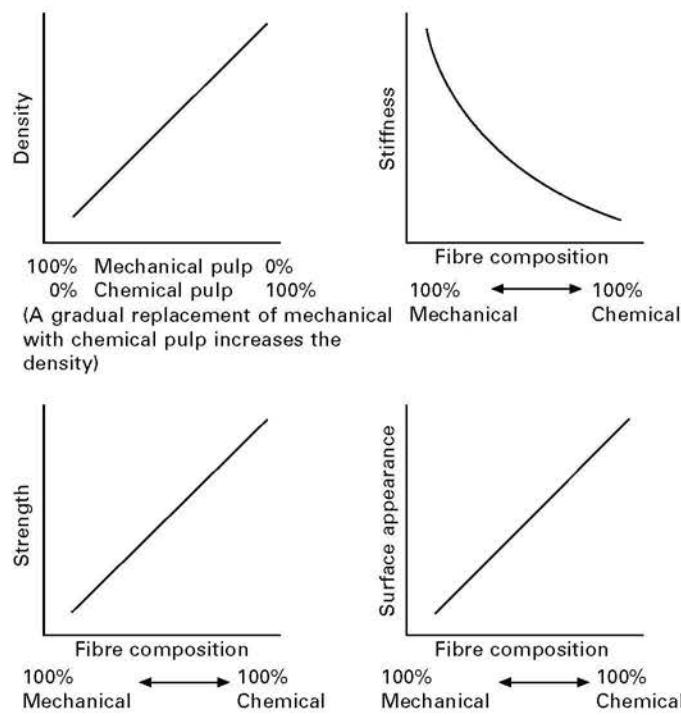
compare four properties of mechanical and chemical fibres it can be seen that

1. density increases as the amount of chemical pulp increases
2. stiffness increases by increasing the amount of mechanical pulp
3. strength increases with increased chemical pulp content
4. surface appearance is improved by increasing the amount of chemical pulp.

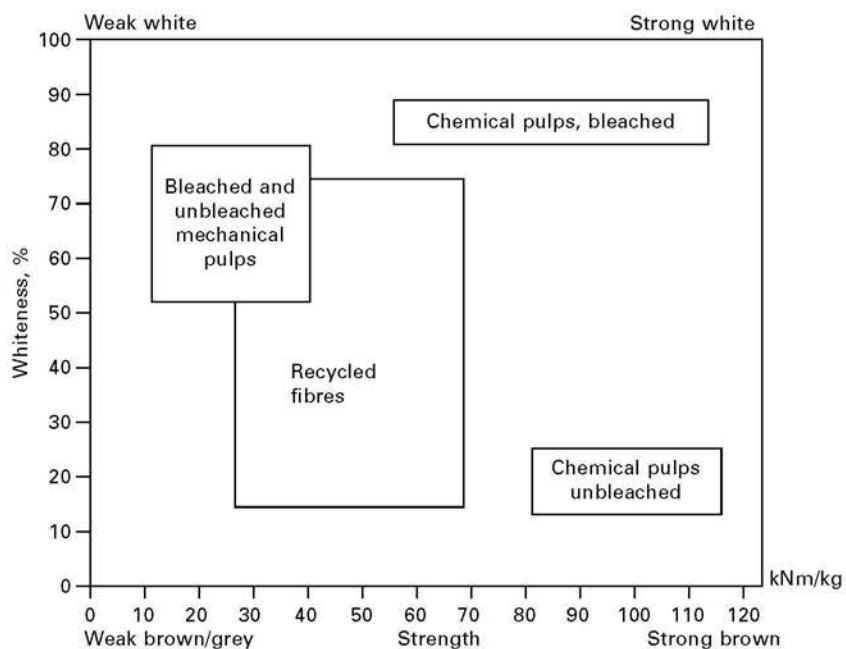
Figure 10.15 compares the properties of recycled fibre with the two main virgin fibres. It can be seen that, in general, recycled fibres are stronger than mechanical fibres but less strong than chemical fibres. The same comparison cannot be used for whiteness. Most recycled fibres are grey in colour. As we change from mechanical pulp to recycled pulp and on to chemical pulp, the density of the paper and paperboard produced from these pulps increases. As density increases it would be expected that strength and surface appearance increase and stiffness decreases. However, as a result of the secondary processing of recycled fibres and the contaminants contained within (clay and chalk coatings, for example) the paperboard made from recycled fibres does not usually follow this expected trend.



10.13 The combination of whiteness and strength for various pulps (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



10.14 Effect on properties of changing types of pulp (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



10.15 Whiteness and strength for different paperboard grades (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

#### 10.2.4 Changing properties by combining paper with other materials

Paper and paperboard, when combined with selected polymeric film materials, can result in materials with significantly enhanced properties. Coating with polyethylene and other polymer films makes it possible to heat-seal paper-based materials, which is very useful in sack and bag manufacture where an integral seal is required, for example for dry pet foods.

Aluminium foil and polymer films can also be added, allowing laminates to be constructed that can be formed into liquid packaging cartons. In these applications the paper provides the stiffness, puncture, and abuse resistance, formability on the packaging machine and adds to the ultraviolet (UV) light barrier. The aluminium provides the gas, UV and water vapour barrier. The polymeric film, usually polyethylene, or polypropylene, provides water and product resistance, acts as an adhesive between the aluminium and the paper, and provides an excellent heat seal to ensure the product does not leak and there is no ingress of gas through the sealed surface.

The negative aspects of combining paper with other materials are that it makes the waste more difficult to separate and therefore recycle into its component parts in a commercially viable manner. Water-based barrier coatings (WBBC) have been developed to overcome some of these issues. They provide water barrier, some water vapour barrier, grease barrier and product release and are claimed to be fully

repulpable with the paper, negating the need for separation of the coating from the fibres.

### 10.3 Raw materials

The main raw material used to make paper and paperboard is cellulose fibre sourced from trees and recycled waste. Fibres are mixed with additives to improve performance and control processes and where necessary treated with coatings to further improve performance. The source for and treatment of these raw materials, and how they influence performance will now be discussed in this section.

Fibre length is one of, if not the most important, property with respect to paper and paperboard performance, and the length and shape of the fibre depends on the source. Deciduous trees, i.e. broadleaf trees which lose their leaves in the winter in non-tropical regions, produce short fibres, whereas coniferous trees, i.e. cone bearing, needle leaf trees, produce long fibres. Deciduous trees are also known as hardwoods and coniferous trees as softwoods. Short fibres provide smoothness for printing while long fibres provide strength. Typical ranges of fibre length used in papermaking are:

- short hardwood fibres: 1–1.5 mm in length
- long softwood fibres: 3–4 mm in length

Aspen, eucalyptus and birch trees grown in temperate climates are the common sources for hardwood fibre, and trees such as spruce, larch, fir, hemlock and pine provide the softwood fibres. All of these types of trees are grown in managed forests with a continuous replanting programme and they are used to make virgin pulp. This important raw material is fully sustainable with minimum adverse effect on the environment. Trees are made up of approximately 50% fibre, the rest being lignin and other substances, such as carbohydrates. Lignin is a complex chemical which binds the fibres together, but also causes discolouration.

Trees of a selected species are grown to a specific size, felled, cut into precise lengths, the branches, twigs and some of the bark removed and the logs transported to the mill to be converted into paper and paperboard. Once the debranched trees reach the mill, they are completely debarked and sent to chippers where they are cut to similar sized small pieces before they are sent to the predetermined pulping process.

Recycled fibres vary widely depending on the waste raw material source. In general they are a mixture of hard and softwoods, their fibre length depending on the number of times they have been recycled. Fibres are shortened at each recycling process and, once virgin fibres have been recycled around seven times, the fibre length is considered too small to use further.

Recycled fibres are often contaminated with printing inks, product and 'contraries' such as plastic, baling wire, wax and adhesive. Although the deinking process can remove some of these, others get through, resulting in contamination of the fibrous sheet produced. These can appear as small particulates of colour, text, grease and char spots and produce a reduced whiteness and brightness as well as reduced

strength (due to the shortening of fibre length) of the finished substrate compared to that manufactured from virgin fibre. However, the industry continues to develop the quality of recycled fibre, with significant improvement over the past 20 years. Some grades of paperboard made from recycled waste are highly competitive in performance compared to virgin paper and paperboard (see Fig. 10.16). Not all properties are worse than virgin papers and paperboards: for example delamination (IGT) and Scott Bond are at least as good, if not better as can be seen from the figure. There is, however, a concern in certain industries where taint, odour, aesthetics and performance are critical.

## 10.4 The pulping process

There are two main types of pulping process for the production of virgin fibre and two intermediate methods. These are mechanical (or groundwood), chemical, thermo-mechanical (TMP) and chemical thermo-mechanical (CTMP or semi-chemical). Recycled fibre is prepared in a separate process using a hydropulper.

### 10.4.1 Mechanical pulp production

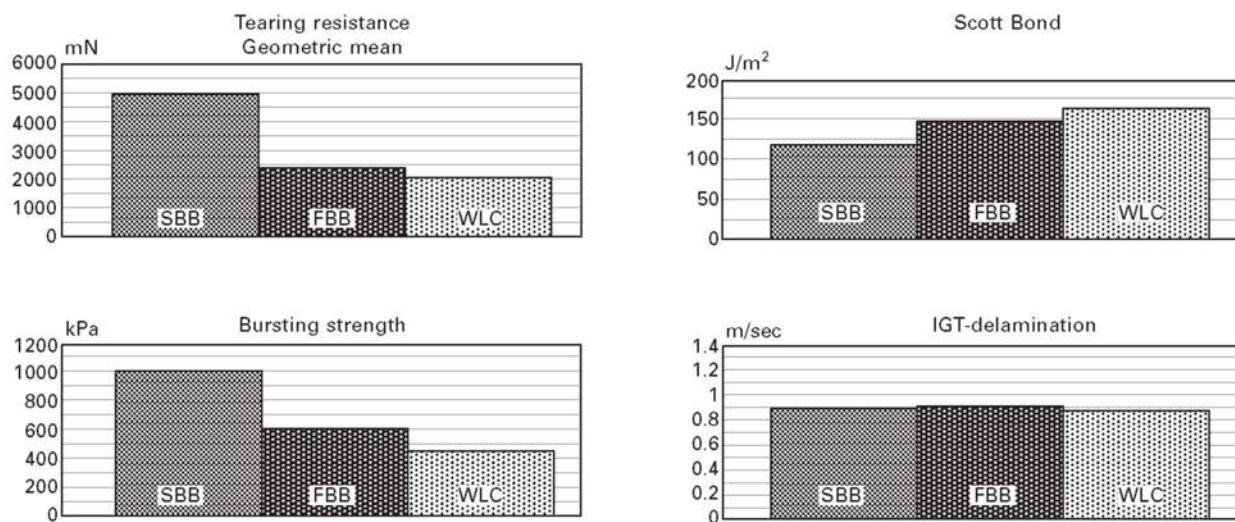
This is the quickest, least costly method of obtaining virgin fibres. The wood chips are washed, to remove any soil, stones or other contaminants, and mechanically ground. The grinding process was traditionally carried out using grindstones similar to those used for grinding flour, to grind the logs directly. This is known as stone groundwood. Nowadays, ridged metal discs called refiner plates are used to process the wood chips. This process separates the fibres individually but in doing so breaks them into shorter lengths. It does not remove the lignin and other impurities, resulting in fibres which discolour with age (see Fig. 10.17).

Mechanical pulp is used for low grade papers such as newsprint and for blending with chemical and semi-chemical produced pulps to reduce costs. It is also used as a sandwich between chemical pulps for the production of folding boxboard (FBB), one of the most popular boards used for carton making in Western Europe.

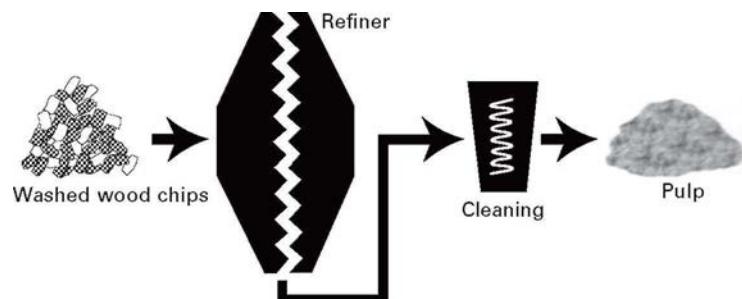
### 10.4.2 Chemical pulp production

Here the wood chips are placed in a digester where the cellulose fibres are separated from the lignin and other impurities using heat and chemicals (see Fig. 10.18). If white fibres are required, bleaching is carried out at this stage. This is the most expensive method of producing fibres for paper and paperboard manufacture, due to the lower yield compared to mechanical pulp and the heat energy and chemicals required. However, it produces the strongest and whitest (when bleached) substrates available.

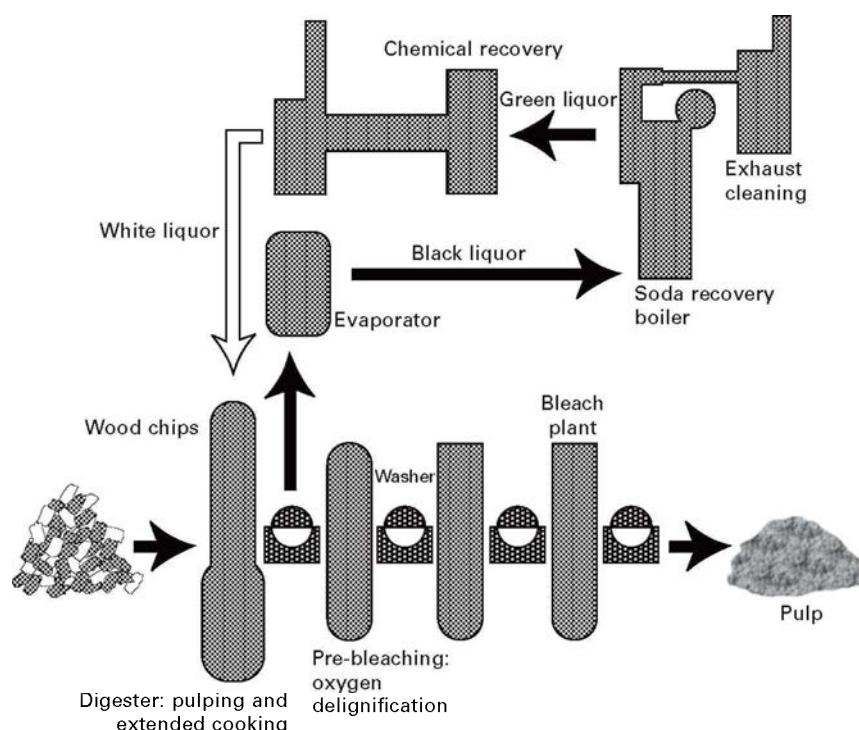
There are two main chemical processes used: the alkaline sulphate process (known as 'Kraft'), which produces the strongest of all the cellulose fibre-based paper and paperboard products, and the acid sulphite process. The sulphate method uses a combination of sodium hydroxide and sodium sulphide in the digestion process. The



10.16 Properties of some paperboard grades made from recycled waste (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



10.17 The production of mechanically separated pulp (adapted from Pro Carton; [www.procarton.com](http://www.procarton.com)).



10.18 The production of chemically separated and bleached pulp (adapted from Pro Carton; [www.procarton.com](http://www.procarton.com)).

sulphite method uses metal or ammonium salts of sulphurous acid, producing either sulphites or bisulphites. These chemicals digest the impurities but, in doing so, due to their acidic nature, hydrolyse some of the cellulose resulting in the final paper or paperboard having less strength than that produced by the sulphate process. However, the amount of pulp produced per hour is greater and the quality of bleaching is better, due to its higher purity. Today less than 20% of all chemical pulp is produced by the sulphite process. However, due to its high purity it is used to manufacture Rayon,

cellulose acetate and Cellophane<sup>TM</sup>. Cellophane<sup>TM</sup>, though not a plastic, is a clear film suitable for packaging of fresh produce, where breathability is a requirement and for twist wrap films for mechanically wrapping individual sweets, where its excellent deadfold properties are utilised.

In Europe chemical pulp can be approximately twice the cost of mechanical pulp (this is not necessarily the case elsewhere, e.g. North America) and is therefore used where maximum strength is required, such as multi-wall sacks and the liners for corrugated cases, especially in damp, high humidity and wet environments. Chemical pulp is also used where maximum toughness, whiteness and purity are required. Examples are the outside plies of folding boxboard, cartons for high value cosmetics and liquid packaging form fill seal cartons. Paper made from chemical pulp is often referred to as 'wood free'. This does not mean the fibres come from material other than trees; it means there is no groundwood or mechanical pulp included in the paper.

The two intermediate pulping processes of TMP and CTMP referred to earlier are used to either improve the properties or reduce the costs of fibre production. In the TMP process, hot water is used to soften the fibres and render them more supple, resulting in less damage during the mechanical process and consequently higher strength compared with the basic mechanical pulping process. The CTMP process, consisting of some chemical digestion and use of heat, but less than in the chemical process, takes less time and therefore reduces total costs. The process partially digests the wood mass, removing some of the impurities prior to mechanically grinding the softened fibres.

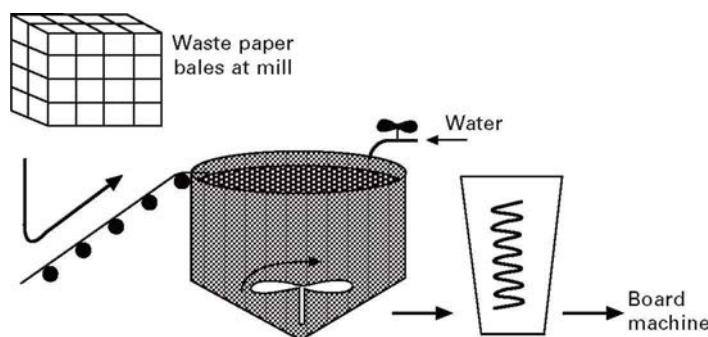
Referring back to Section 10.2.3, and taking into account the fibre length as well as the pulping process, natural (unbleached) Kraft made from softwood fibres produced by the chemical sulphate process is the strongest paper or paperboard available, and mechanical or groundwood pulp made from hardwood fibres produces the weakest paper or paperboard available. Packaging formats are produced from combinations of fibre and pulping processes to meet the performance requirements of the final pack, taking into account the needs of the whole supply chain (see Table 10.2).

Virgin pulp is not always produced at the mill that makes the final paper or paperboard. Many small and some large mills buy in some or all of their pulp and disperse it into water using a hydropulper. This is a large vessel with an agitating

Table 10.2 Pulp preparation

Pulp preparation	% lignin removed	Yield	Process
Mechanical	nil	95%+	Grinding
Thermo-mechanical	nil	95%+	Steam heating + Grinding
Semi-chemical	10–80%	65–85%	Cooking with chemicals + Grinding
Chemical	80–90%	45–65%	Cooking with chemicals
Chemical + Bleaching	100%	45–55%	Plus bleaching agents
Dissolving	100%	45–50%	Plus sodium hydroxide (cellulose film)

blade. The pulp, often in the form of large sheets, is dropped into the water contained in the vessel and dispersed in it to the required concentration – between 0.3 and 3.0% depending on whether paper or paperboard is the intended product. The higher concentrations are used for paperboard. The dispersion of fibre in water, plus the other additives and process aids, is known as the ‘furnish’ (see Fig. 10.19). This will be covered in more detail in Section 10.7.



10.19 Pulp production using a hydropulper (adapted from Pro Carton; [www.procarton.com](http://www.procarton.com)).

#### 10.4.3 Recycled fibre production

Recycled pulp is also produced by using a hydropulper. Selected, de-inked waste paper and paperboard is dispersed in water in the same way as pre-formed sheets of virgin pulp as described above. For every tonne of waste material, less than 90% is recovered, the loss being due to material being unfit for use and having to be discarded, and to the de-inking and other cleaning processes, which result in a loss of fibre. Recycled pulp is usually much more price competitive than virgin pulp, but produces an inferior product, both from a performance and an aesthetic viewpoint as already discussed. That does not mean it is not fit for the purpose for which it is intended.

Some recycled paper and paperboard materials need to be supplied at up to 20% greater basis weight to provide the same performance characteristics, compared to some virgin paper and paperboards. Paperboards made from recycled materials are referred to as waste-based board (WBB) or coated recycled board (CRB) or white lined chip (WLC). There are other terminologies used in some European countries (see Section 10.2.2).

### 10.5 Post-pulping treatment of fibres to improve performance

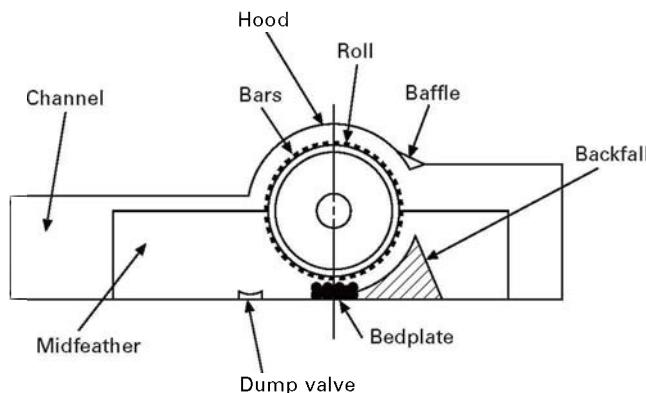
Once the fibres have been extracted by any of the above pulping processes, they are still not in the shape and condition required and further treatments are carried

out. The main two post-treatments of fibre are beating and refining (one process) and bleaching.

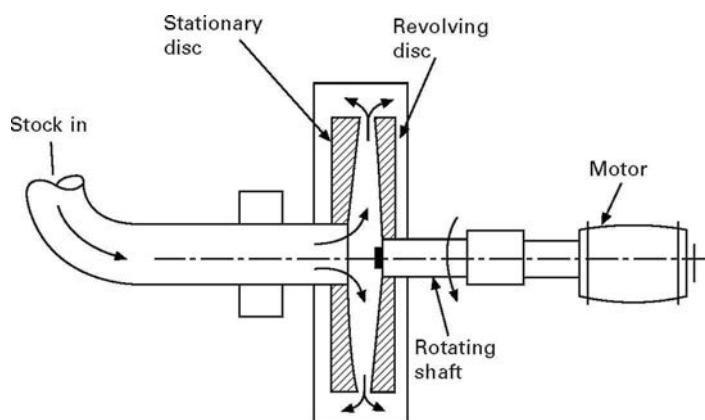
### 10.5.1 Beating and refining

The beating and refining of fibres is one of the most critical processes in the production of paper, and to a lesser extent paperboard (see Fig. 10.20). The process bruises/splits the fibres, increasing their flexibility and extends their surface coverage, but in doing so reduces fibre length distribution, weakening the overall paper or paperboard.

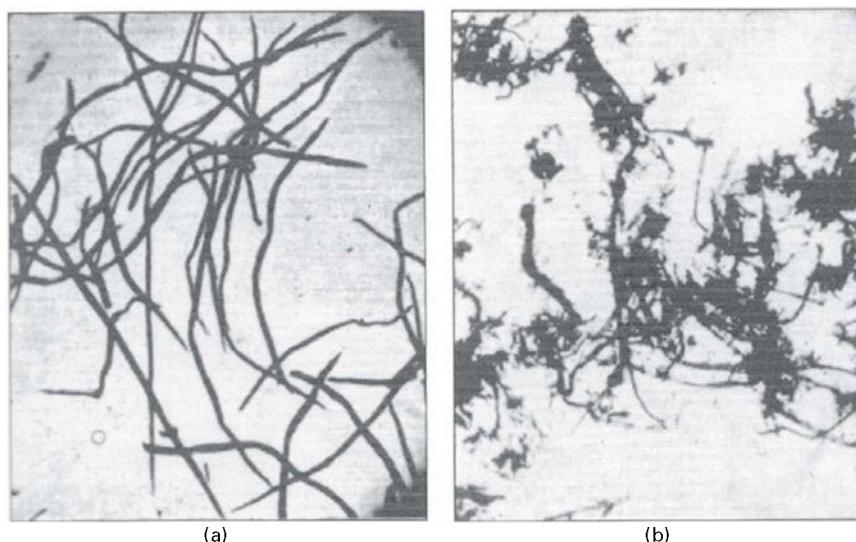
Refining is carried out as part of the stock preparation process, by passing the pulp, suspended in water, across rotating surfaces. This causes the fibres to fibrillate and swell. This process is either continuous (where minimal refining is required) or a batch process (where considerable beating is required to produce greaseproof and glassine grades of paper). The latter uses a more sophisticated beating process where the fibres are passed through rotating discs or cones (see Figs 10.21 and 10.22).



10.20 Beating of fibres (source: Paper Industry Technical Association (PITA); [www.pita.co.uk](http://www.pita.co.uk)).



10.21 Rotating disc refiner (source: Paper Industry Technical Association (PITA); [www.pita.co.uk](http://www.pita.co.uk)).



10.22 Fibres before (a) and after (b) beating (source: Paper Industry Technical Association (PITA); [www.pita.co.uk](http://www.pita.co.uk)).

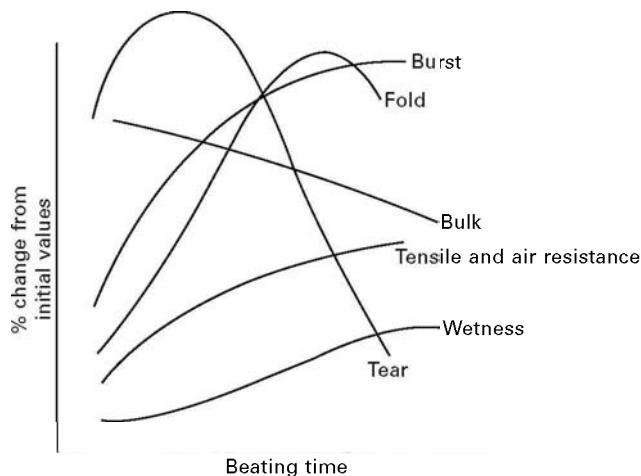
While refining the fibres improves the paper properties, too much refining will lead to deterioration. As the process is prolonged:

- burst, tensile strength and resistance to the permeation of air through the substrate of air all increase
- tear resistance increases initially, but quickly decreases as fibres reduce in length
- resistance to folding increases initially but then reduces as fibres decrease in size
- uniformity of paper increases, resulting in improved print surface and formation (appearance), all as a result of reduced fibre length induced by the refining process (see Fig. 10.23).

### 10.5.2 Bleaching

Bleaching is another post-treatment of fibres, carried out once the fibres have been separated from their source. Paper and board produced using bleached pure cellulose made by chemical pulping has a bright, white appearance and shows little or no tendency to fade or yellow when subjected to sunlight. Mechanical pulp, even if bleached tends to yellow over time.

Traditionally bleaching was done using chlorine, which dissolves some of the lignin remaining in pulp. However, due to the environmental disadvantages and potential safety hazards of using chlorine, the amount of pulp bleached in this way has declined. It is currently thought to be around 25% worldwide, the remainder having been replaced by one of two common processes:



10.23 The effect of beating on paper and paperboard properties (source: Paper Industry Technical Association (PITA); [www.pita.co.uk](http://www.pita.co.uk)).

- *ECF – elemental chlorine free*. The bleaching sequence uses chlorine dioxide, with no use of chlorine gas or sodium hypochlorite. It is sometimes known as chlorine dioxide bleaching (CDB).
- *TCF – totally chlorine free*. Here the bleaching sequence uses only oxygen-based chemicals such as oxygen, ozone and alkaline or acidic peroxides. It is sometimes known as oxygen chemical bleaching (OCB).

A further category, specific to recycled paper is known as PCF – process chlorine free. This indicates that, while the production of the primary fibre may have involved the use of chlorine and chlorine compounds, these materials are not used during the recycling process; the fibre is either not bleached at all, or if bleaching has been carried out it is done using oxygen-based systems. This is sometimes known as secondary chlorine free (SCF). Both ECF and TCF processes are vast improvements on those which use chlorine. TCF claims to use less toxic starting chemicals than ECF, and to have a reduced environmental impact. However, TCF pulps generally have lower strength properties than ECF pulps, although this can be compensated for by lower brightness, if this is aesthetically acceptable. Another consideration is that the number of mills producing TCF papers is much lower than those producing ECF and is currently thought to be around 7%, mostly in Northern and Central Europe.

### 10.5.3 Additives

Paper and board are not produced by using fibres alone. Additives and process aids are required to ensure that the important properties required by the converter, packer/filler and end user are controlled consistently.

The types of additives used in paper and board manufacture and their purposes are discussed below:

- Fillers such as kaolin and chalk are added to the furnish to improve printability of the paper, and others such as titanium dioxide are added to improve whiteness. Fillers also improve surface smoothness, control brightness and control opacity. They are also used to reduce the cost of manufacture of the paper and paperboard.
- Pigments may be added to colour the paper, although the range of shades available is limited and most coloured effects are achieved by surface printing.
- Whitening (FWA – fluorescent whitening agents) and brightening (OBA – optical brightening agents) are also added to improve the whiteness, especially under retail lighting.
- Binders such as starch (farina from potatoes, maize, wheat and tapioca) are used to increase strength by linking the fibres together restricting their movement and resulting in a unified mat. Binders are also used to prevent the fillers falling out of suspension in the furnish.
- Size is used to control water and ink penetration and its use is crucial to address problems due to the natural absorbency of cellulose fibres. Totally unsized papers would allow ink to soak in and spread throughout the fibres. Sizing agents used are, for example, AKD (alkyl ketene dimer), aluminium sulphate ('Alum'), modified starch and gelatine for surface sizing and AKD, ASA (alkenyl succinic anhydride), rosin and 'Alum' for internal sizing. Surface size is added to the paper web using a size press and can be applied to one or both sides depending on the final properties required of the substrate. Internal size is added to the furnish before the paper is formed. AKD is an amphipathic lipid, i.e. a molecule which is mostly non-polar (hydrophobic) in structure, but at one end having a region that is polar or ionic (hydrophilic). The hydrophilic region is usually referred to as the head group, and the hydrophobic portion is known as the tail. They work by surrounding the fibre with the hydrophobic tails outermost, pushing the water away from the fibre and thus reducing the amount of water that will penetrate the fibre. Size can vary in pH from acidic through neutral to alkaline and as a result the choice of sizing agent also controls the pH of the final substrate.
- Wet strength resins, based on urea and melamine formaldehyde, can be added to reduce the effect of water on the initial strength of the paper. An example would be paper for multi-wall sacks for use outside, or for carrier boards used for collating packs in wet conditions such as for bottled carbonated beverages.
- Grease resistance can be achieved with additives. Fluorocarbon chemicals can be added, either to the furnish or at the size press. They work by surrounding the cellulose fibres and protecting them from any oil or grease which may penetrate. They have been used in the past for the production of dry petfood bags, sacks and cartons, where the fat content of the product is often over 20 percent. They have also been used in the manufacture of wrapping paper for butter and margarine, replacing the traditional parchment paper. Concerns about taint and odour have greatly reduced their use in recent years.
- Other chemicals such as acrylic resins are added to improve water resistance and wax to improve strength and water resistance, the latter becoming much less common due to issues with recycling of the waste material.
- Process aids are also necessary. These include anti-foaming agents, bactericides

(restrict microbiological activity), flocculating agents (improve dewatering of the furnish as the web is formed) and special chemicals to reduce/prevent the resins from the wood depositing on the paper web, possibly causing web breaks and contamination both during papermaking and in the later printing processes.

The fibre and the additives are now suspended in water and fed into the mill ready for the manufacture of paper and paperboard.

## 10.6 The manufacture of paper and paperboard

The principles of papermaking are basically the same today as they have always been, with three distinct stages:

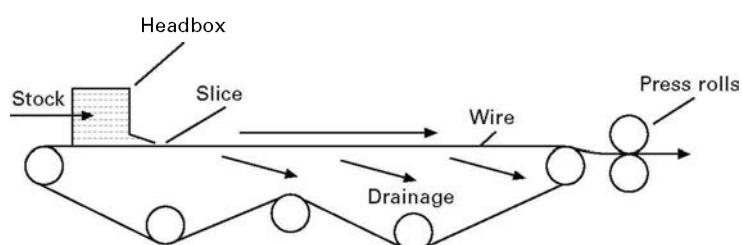
1. A dilute suspension of fibre and additives in water is prepared.
2. The dilute suspension is formed into a sheet of intertwined fibres.
3. Water is removed at all stages of the process, via drainage, pressure, vacuum and evaporation, until a suitable substrate is achieved.

Although there are many variations of individual paper and paperboard making machines, they are all made up of a wet end, where the sheet is first formed, and the water is removed by mechanical means, and a dry end, where heat is used to bring the substrate to its required moisture content, and a number of surface treatments are carried out. There are two main types of paper or paperboard mill discussed in this chapter:

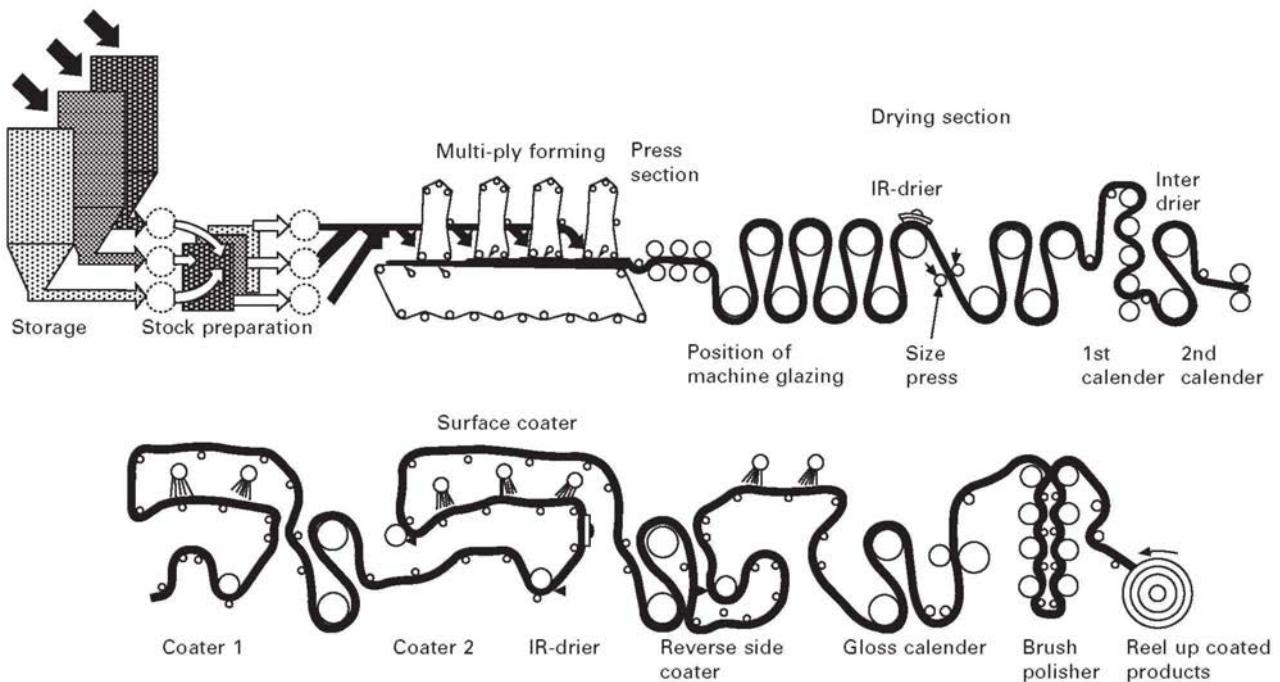
- wire or Fourdrinier
- vat or cylinder

### 10.6.1 The Fourdrinier method

The principles of paper and paperboard manufacture by the Fourdrinier process are very similar (see Figs 10.24 and 10.25). Dilution of fibre in water varies from 0.3 to 3% depending on the weight of paper or paperboard being manufactured. Weights vary from 12 gsm for the lightest tissue paper to 600 gsm for solid bleached paperboard



10.24 Fourdrinier papermaking process: basic wire process (adapted from Kirwan, M.S. (ed.), *Paper and Paperboard Packaging Technology*, Blackwell Publishing Limited, Oxford, 2005. Reproduced with the permission of John Wiley and Sons Inc.; [www.wiley.com](http://www.wiley.com)).



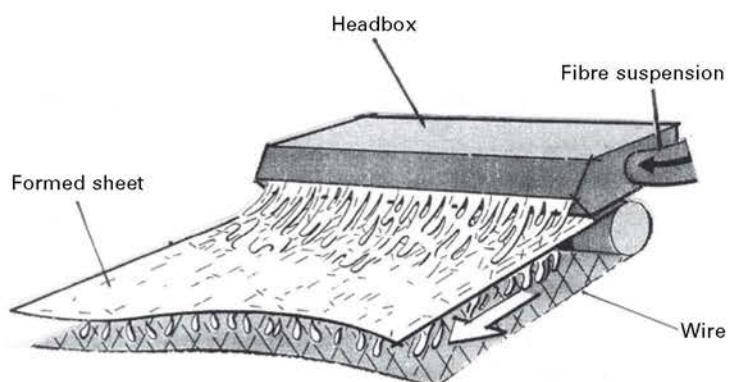
10.25 Fourdrinier papermaking process using multi-formers (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

made from chemical pulp. The heavier the paper/paperboard being manufactured the higher the concentration of fibre in water.

The furnish is held in tanks, each tank holding a specific fibre and additive combination and it is fed into a headbox, which in turn spreads it onto a wire via the slice, which controls the flow (see Fig. 10.26). Today the 'wire' is a plastic mesh. The first layer of fibre, which may be the only layer if making paper and will be the underlayer if making multi-layer paperboard, is delivered onto the wire as consistently as possible. The water drains away through the wire, usually assisted by vacuum suction boxes. The movement of the wire means that the fibres align themselves preferentially in the direction of travel, i.e. the machine direction (MD). This is not ideal as the aim is to produce a sheet where there is no obvious fibre alignment. To try and achieve this aim, the wire is often shaken in the cross direction (CD), to redistribute the fibres.

Depending on the final thickness/weight of the paper/paperboard, other layers are added until the required specification is reached. Each additional layer requires another headbox and slice to deposit the fibres on top of the other layer(s). However, as the layers build up, the rate at which water will flow through the wire decreases significantly and it is necessary to use top wires where the water is sucked upwards using vacuum. Sometimes the last layer (top layer) is formed as an independent sheet and added to the rest of the construction as a final operation. The moisture content of the paper or paperboard is still high at this stage at around 60–70%.

The wet substrate is then sandwiched between felt blankets and passed through the press section where steel rolls remove more water by pressure and vacuum from the fibrous web. The web then passes to the dry end of the machine, firstly through the drying section where more water is removed by evaporation using steam heated steel cylinders. At this stage it can pass over a large polished metal cylinder resulting in a smooth surface finish being produced without compressing the web, which would reduce its thickness and stiffness. This type of finish is known as MG (machine glazed).

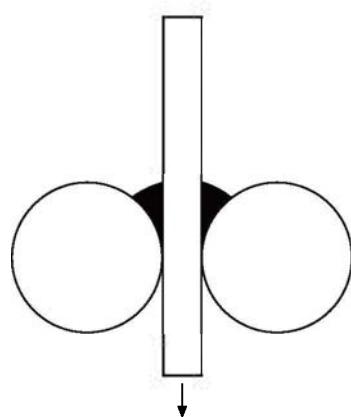


10.26 Fourdrinier forming process: headbox and slice (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

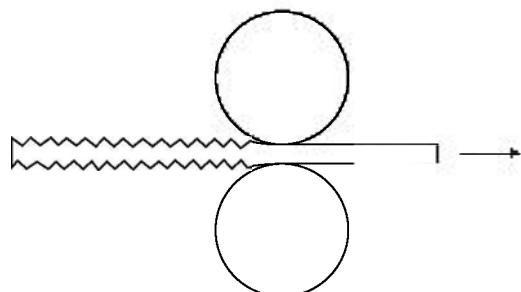
Immediately after the drying section, surface sizing can be carried out using a starch solution which can be pigmented if required. This prevents fibres shedding from uncoated surfaces and improves surface strength and smoothness, hence printability (see Fig. 10.27).

Calendering, which is a type of ironing process giving a uniform thickness and smoothness to the paper or paperboard, takes place once the substrate has been sized. The dry substrate is passed between cylinders, which can be cold or heated and water may be applied to enhance the smoothing effect. The cylinders on paper machines are often a combination of steel rolls and ones made of composite material to provide very smooth glossy finishes. Some papers are produced by 'super calendering' (e.g. glassine), which is carried out on a separate machine having up to 14 rolls, to produce a translucent paper (see Fig. 10.28).

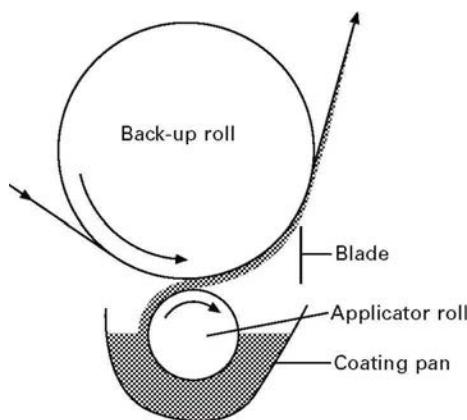
Where required, the web is now coated with a white mineral pigment base (clay or chalk). This gives a hard smooth surface suitable for high quality printing. There are many ways to add the coating and, depending on the colour of the web (brown, grey or white), between one and three separate coats are applied. The amount of coating is also governed by the final smoothness required and the initial smoothness of the web. The smoother and whiter the web initially, the less coating is required (see Fig. 10.29).



10.27 Size press (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



10.28 Calendering (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

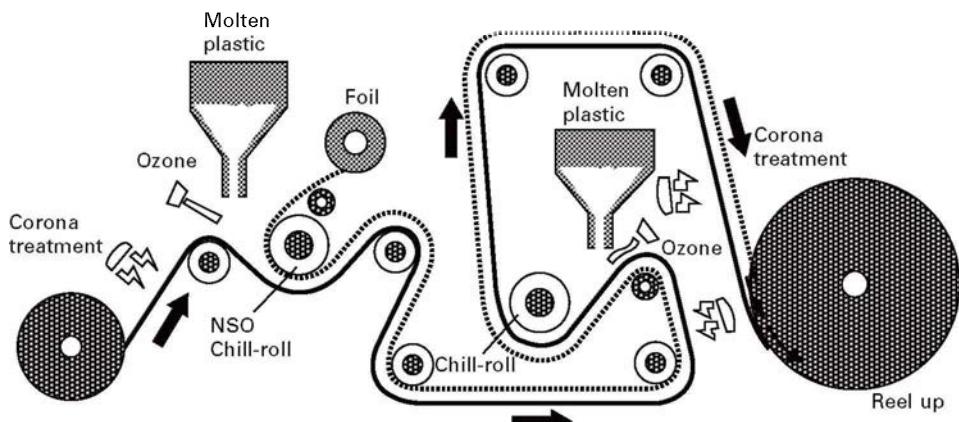


10.29 Blade coating (source: Paper Industry Technical Association (PITA); [www.pita.co.uk](http://www.pita.co.uk)).

The quality of the coated surface is influenced by the mechanism by which the coating is applied, with the double blade process giving superior results to those using an air knife. Binders are used to achieve good adhesion between the coating and the base web, and between the mineral particles within the coating. Optical brightening agents may also be added to the clay coatings especially for cartons for retail display.

Once the coatings have been applied, the material is ready to be wound up into reels. The web is wound on cores in batches of up to 20 tonnes. These 'parent' or 'mother' reels are wrapped in protective coverings and labelled to ensure product identification and traceability. The mother reels can be slit into the required widths, either *in situ* on the mill or during a separate operation, after the mother reel has been removed from the end of the mill. They are then stored under controlled conditions of temperature and humidity awaiting conversion. If the material is going to be converted into folding cartons and printed via the offset lithographic process, it is often sheeted into various sizes, before being wrapped, labelled and stored.

Not all coating processes are carried out in-line on the paper or paperboard making machine; in some cases manufacturers take the slit reels and apply coatings separately. One example is cast clay coating applied to paper destined for high grade label stock to give a very high quality smooth surface. Other coatings such as wax or synthetic polymers can be applied, either on or off the paper or paperboard making machine. Wax can be applied as an emulsion or as a molten liquid. Where both sides are coated at the same time, a process known as 'cascade coating' is used and where just one surface is coated this is done using 'curtain coating'. Wax coating makes the material difficult or impossible to recycle, but gives it good water and grease resistance, allows it to be heat sealed and adds extra strength and deadfold characteristics. Polymer coating using plastic films has largely superseded wax. This is applied either as an extrusion coating or is laminated to the paper via an adhesion process (see Fig. 10.30). (This will be covered in more detail in Chapter 14.)



10.30 Extrusion coating and lamination (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

Polymer films hinder recyclability as they have to be removed at or before the hydropulper. However, correct selection of polymer film can add to the benefits of paper and paperboard, providing barrier to moisture and gas (especially in combination with aluminium foil), grease resistance, water resistance, heat sealability, high gloss finish, and, using reverse print techniques, protection of the decorated surface.

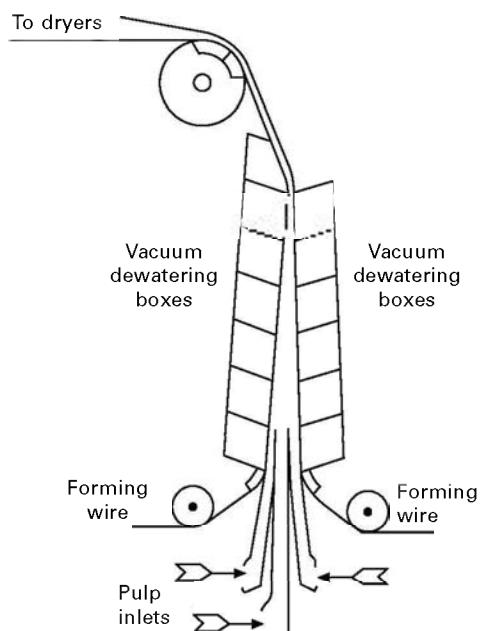
In the past 15 years water-based functional coatings (generally known as WBBC – water-based barrier coatings) have been developed, which when applied to the surface of paper or paperboard can provide similar protection to fluorocarbon, wax and polymer films, but allow the coated substrate to be easily repulped without leaving any undesirable residues. This enables them to be placed in the same waste stream as uncoated paper and paperboard.

Returning to the wet end of the papermaking machine, a variation of the Fourdrinier method is the vertical former ('Vertiformer') which is a twin wire former. The furnish is supplied to the space between the formers, and picked up by two meshes (wires); the water is removed from both sides of the paper by the two wires. This has two advantages:

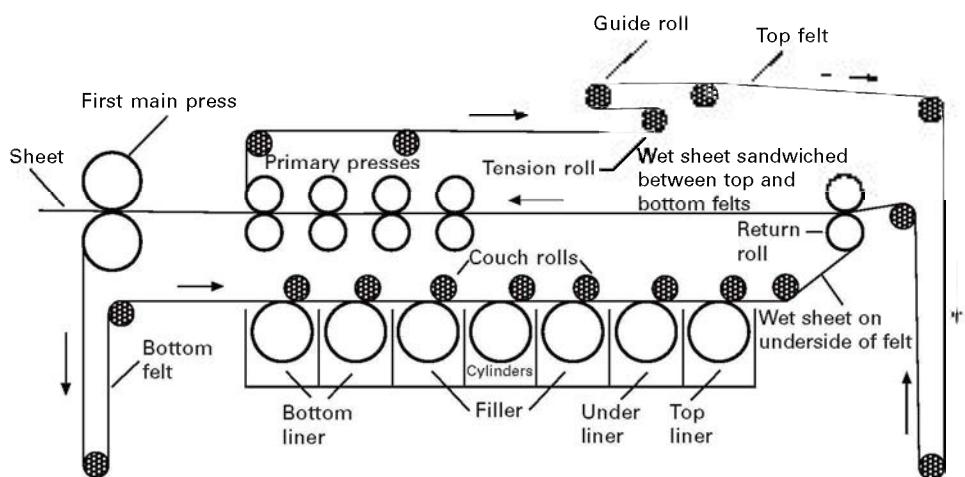
- the paper can be produced at a faster speed than when using the horizontal wire method as dewatering is quicker, and
- two ply papers can be produced with identical finishes on both faces (see Fig. 10.31).

### 10.6.2 The cylinder (vat) method

The second major method of manufacturing paper and paperboard uses individual vats containing the furnish required for each layer (Fig. 10.32). A large screen drum revolves within the vat and as it does so it picks up the fibres and the excess water drains away through the screen, leaving fibre on the outside surface of the screen. This fibre is transferred from the screen onto the underside of a continuous moving



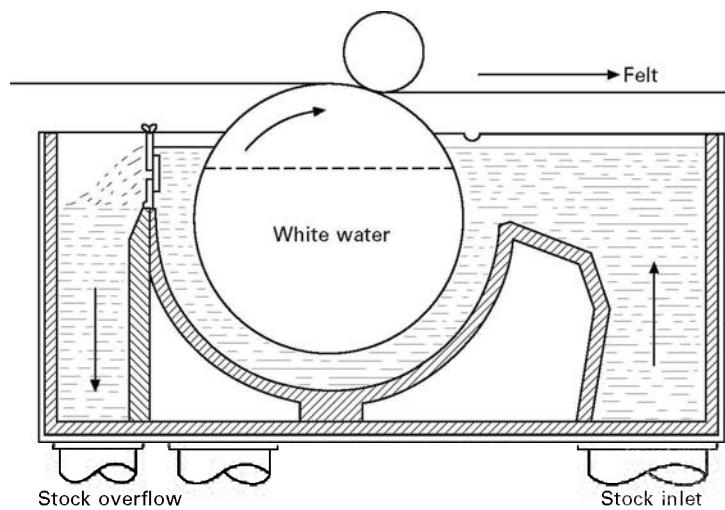
10.31 A vertiformer.



10.32 Vat paperboard machine.

felt. The felt then passes over the next vat where a second layer is added to the first and so on, until the final specification is achieved. Different pulp fibres, e.g. chemical, mechanical, recycled, can be added via the individual vats to build up a multilayer structure.

The cylinder has a differential pressure between the inside and outside which assists in dewatering. The furnish can flow in the same direction as the cylinder rotates ('uniflo'), as shown in Fig 10.33, or it can flow in the opposite direction,



10.33 A 'uniflo' vat cylinder (source: Paper Industry Technical Association (PITA); [www.pita.co.uk](http://www.pita.co.uk)).

known as 'contraflo'. The uniflo method results in an even, consistent sheet formation, whereas the contraflo method allows a greater amount of fibre to be deposited on the cylinder, resulting in a thicker and heavier board being produced for the same number of vats used. However, the interply bond strength using contraflo is weaker than with uniflo. Also the interply bond strength of cylinder paperboard is generally weaker than paperboard produced by the wire method.

Once all the layers have been applied to the felt, a second felt is placed on the top of the fibrous web (see Fig. 10.32) and the whole is passed through a series of presses which remove sufficient water for the web to be self-supporting and the felts to be removed. From here the dry end section is the same as for the wire method.

#### 10.6.3 Control of quality of paper and paperboard

During paper and paperboard making, controls must be put in place to ensure a consistent substrate is produced which is stable in use. Tests are carried out on and off the machine to ensure conformance with specification and adjustments made to address any unacceptable deviations.

Consistent moisture content is critical and this is monitored on the machine using infrared sensors. These transmit signals to control the activation of aspirated sprays to stabilise the moisture content of the web. Moisture content, thickness, basis weight and stiffness are constantly monitored in the mill laboratory and adjustments made to the machine to ensure the parameters stay within the limits of the specification. It is, however, important to recognise that paper and paperboard have different properties when measured in the cross and machine direction:

- substrates made by the wire method have a MD:CD ratio in the region of 2:1
- substrates made by the vat method have a MD:CD ratio in the region of 4:1.

The relationship between the two directions is a complicated one. It is not just the MD stiffness that needs to be taken into consideration but the CD as well.

Various tests which may be carried out on paper and paperboard to ensure it provides the appearance and performance expected are described in Tables 10.3 and Table 10.4. Most tests are carried out under controlled conditions of temperature and humidity to ensure they are repeatable and completely comparable. The international standard for test conditions is 23°C and 50% RH. When comparing values, the units and test conditions should also be scrutinised to ensure a realistic comparison.

## 10.7 Conversion processes for paper (<250 gsm)

The most common papers used in packaging and typical end uses are:

- Kraft: bags, sacks, folding cartons, corrugated liners
- sulphite: bags, sacks, folding cartons, dual ovenable trays, liquid packaging, labels, leaflets, corrugated liners
- CTMP: corrugated fluting medium, liquid packaging containers
- test liners (mixture of virgin and recycled fibres): corrugated liners
- recycled Kraft: spiral wound containers
- greaseproof, glassine and parchment: wrappers and bags where grease resistance is important
- tissue: tea bags, industrial packaging, fine jewellery, textiles.

The main packaging formats using paper are:

- corrugated packaging (this is the largest use of paper in packaging and is covered in Chapter 11)
- sacks
- bags
- spiral, linear and convolute wound containers
- liquid packaging cartons.

### 10.7.1 Paper sacks

A paper sack can be differentiated from a paper bag by its product weight which is usually >5 kg and the fact that it is traditionally made from more than one ply. In the United States paper bags are used as grocery bags referred to as sacks. Paper sacks are traditionally made from between two and six plies of paper, sometimes having one plastic film ply to resist the ingress of water, for example cement sacks for use on open air building sites. Modern developments in sack Kraft papers have led to some sacks being produced from one ply of heavyweight Kraft (circa 120 gsm).

The sack manufacturing procedure is straightforward. The plies of paper, fed from separate reels, are passed through a tubing machine where each one in turn is glued with a water based emulsion adhesive to produce a multi-wall tube in which each ply is free to move independently. This freedom of movement of the plies allows the sack to remain flexible and absorb the bursting forces which would otherwise rupture a more rigid construction. The tube is cut to size and the bottom formed

Table 10.3 Tests carried out for surface appearance

Test	Explanation	Test method
Surface strength	Determination of resistance to picking – for coating and printing it is important for the surface of the substrate to be stable	ISO 3783-2006
Surface tension	This method is used to determine how easily a surface wets out. A good surface energy is required to ensure adhesives and inks do not reticulate on application	ISO 8296
Whiteness	Determination of CIE (International Commission on Illumination) whiteness. A measure of how white a surface is – whiteness affects the final brightness of an ink printed upon it. Not suitable for fluorescent-treated paper and paperboards	ISO 11476-2000
Brightness	Measures the reflectance from fluorescent-treated paper and paperboards – important for products sold under fluorescent light source – for example in supermarkets	ISO 2470.2-2008
Opacity	Measures the amount of light which passes through a paper or paperboard by diffuse reflectance	ISO 2471-2008
Surface roughness	Bendtsen method of measuring how smooth the surface of a fibre substrate is by recording the rate at which air leaks between the test piece and the substrate surface	ISO 8791.3-2005
Porosity	The Bendtsen method measures the amount of air which will pass through a substrate in a given time. This is important as porosity determines how much coatings will penetrate and how easily a vacuum sucker will hold the substrate in place	ISO 5636
Gloss	Measurement of reflectance from a standard beam of light shone at an angle of 20° to the substrate	ISO 8254.3-2004
Rub resistance	A measurement of how resistant a printed or coloured surface is to abrasion from a predefined surface, e.g. paper	ISO 105-X12-2001
Surface pH	pH is the measurement of hydrogen ion concentration in water. It is scaled from 1 to 14. 1 is high acid, 14 high alkaline and 7 is neutral. The pH of the surface of a paper or paperboard substrate affects its performance	Tappi T529 om 09
Ink absorption	A measurement of the ability of a coated surface to absorb ink	Tappi T553

and sealed. Sealing can be by stitching, pasting with adhesive or heat sealing, where hot melt, polymer film or other heat seal coating is incorporated onto the sealing surface. There is a wide range of sack designs starting from simple open mouth to block bottom, gusseted valve sacks.

Open mouth sacks can be supplied as sewn flat (a); sewn gusseted (b); pasted

Table 10.4 Tests carried out to control performance properties of paper and paperboard

Test	Explanation	Test method
Thickness	Thickness is important for evaluating the density of the substrate and for printing. Printing requires an even thickness of substrate to ensure an even depth of print	ISO 534-2005
Basis weight	This is a method for accurately determining the number of grams in a square metre of paper or paperboard	ISO 536-1995
Water absorption (Cobb test)	Water penetration (absorption) is critical for many applications. The usual way of measuring this criteria is the Cobb method. This requires a given amount of water at a given temperature to be placed on a known area of substrate for a given period of time. The amount of water absorbed by the substrate over a given time is recorded. This time can vary from 1 minute to 30 minutes, depending on the expected absorbency of the substrate	ISO 535-1991
Moisture content	Paper and paperboard contain moisture. Control of the moisture content across the web is critical as is even drying, if a stable paper or paperboard is to be achieved. Moisture content can be tested in many ways, a quick method where the moisture is driven out of the substrate using a hot plate or iron or a more controlled, but time-consuming method where the test specimen is placed in an oven, set at 105°C until constant weight is achieved. The quick method is used on machine and the more accurate method for quality assurance	ISO 287-1985
Bending resistance/stiffness	Stiffness and resistant to bending must be measured in both the cross and machine directions. The stiffness of a paper or paperboard can be used to predict the compression strength of a package once the width, depth and height are known, and the ability to maintain the shape of the final package	ISO 2493-1992 ISO 5628
Short span compression strength	This is one criterion which has been developed over the years to provide better guidance for final compression characteristics than stiffness	ISO 9895-2008
Tensile strength (dry)	Paper substrates in particular need a tensile strength high enough to ensure they will run through the converting process without breaking. It is not just the breaking point that is important but the elongation at break (how much it has stretched). This is especially important for 'sack Kraft'. Tensile and burst strength are among the most important quality control properties for paper manufacture. Tests are carried out in the wet condition as well as dry, especially for wet strength papers and sack Kraft	ISO 1994.2-2008
Burst strength	This is a very useful test when determining how paper sacks and bags will resist bursting open if dropped or in normal handling (cement sack for example)	ISO 2758-2003
TEA (Tensile energy absorption)	This is a test used on sack Kraft. High performance sack Kraft paper must be strong, with high tensile energy absorption (TEA). TEA can be defined as the area under the tensile-elongation curve and is therefore a combination of total tensile strength and stretch of the pulp	ISO 1294
Elmendorf tear resistance	Tear resistance helps to evaluate how the substrate will perform in use. Controlled tear resistance in both MD and CD is important to ensure that packages open in use but do not tear unnecessarily when being converted	ISO 1974-1990

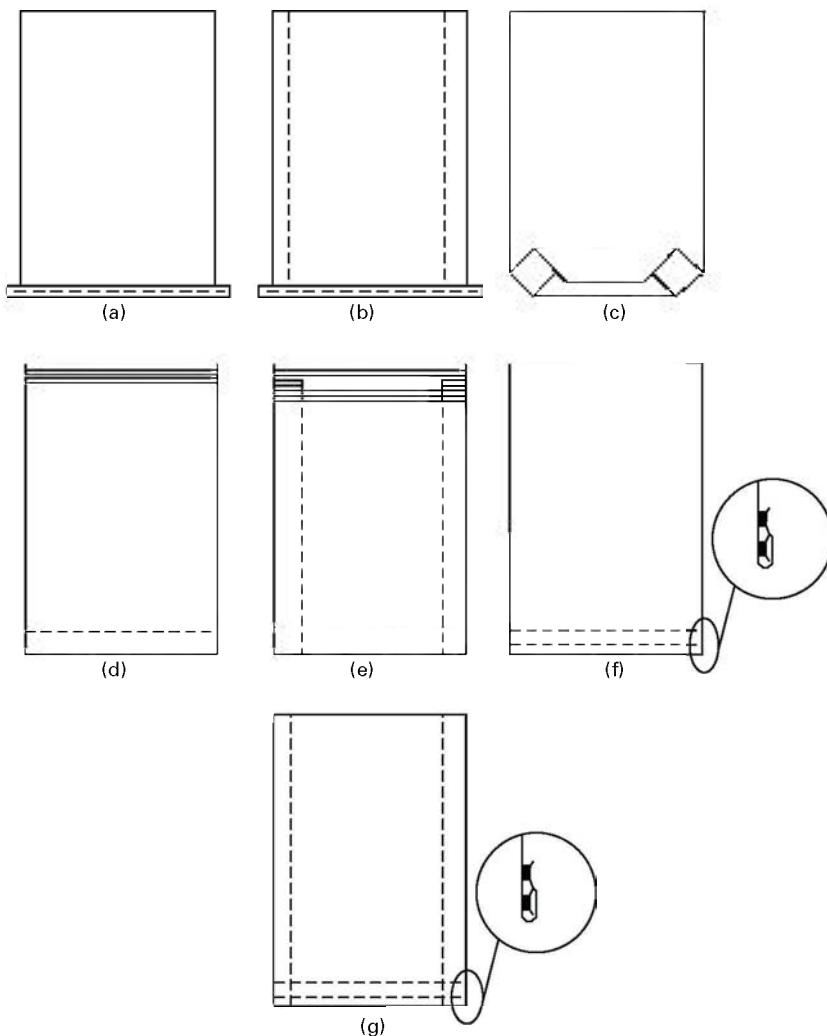
Table 10.4 Continued

Test	Explanation	Test method
Interply bond strength (z direction tensile strength)	Interply bond strength is important. During manufacture the plies of fibre interact with each other and bond (hydrogen bonding). The strength of this bond needs to be greater than the rupturing forces applied during processing. Paper and paperboard made by the vat method is generally weaker in the z direction than that made by the wire process. If the interply bond strength is too weak, multi-ply paper and paperboard will delaminate during the conversion process	ISO 15754-2009
Coefficient of friction	Although this test was introduced for plastics, it is very useful to determine the resistance to slip of a paper or paperboard product	ISO 8295-1995
Taint and odour Robinson sensory test	This test has been incorporated into the EN legislative protocol to assess whether paper and paperboard products are fit to be used for direct food contact. It is a sensory subjective test, but extremely important for high fat and bland foodstuffs where taint and odour can be transmitted from the paper and paperboard unless controlled. Tainting and odorous chemicals contained in paper and paperboard substrates can be identified by using chromatography	EN1230.2-2001

flat (c); pinched closed flat (d); pinch closed gusseted (e); pasted double folded flat (f); pasted double folded, gusseted (g) (see Fig. 10.34). Plastic film layers can be included and, if this plastic film is the innermost ply, the sack can be heat sealed. The non-gusseted versions are like a pillow in shape when filled and therefore require care when being palletised due to their instability. They are commonly used for the packing of animal feeds and powdered foods and ingredients.

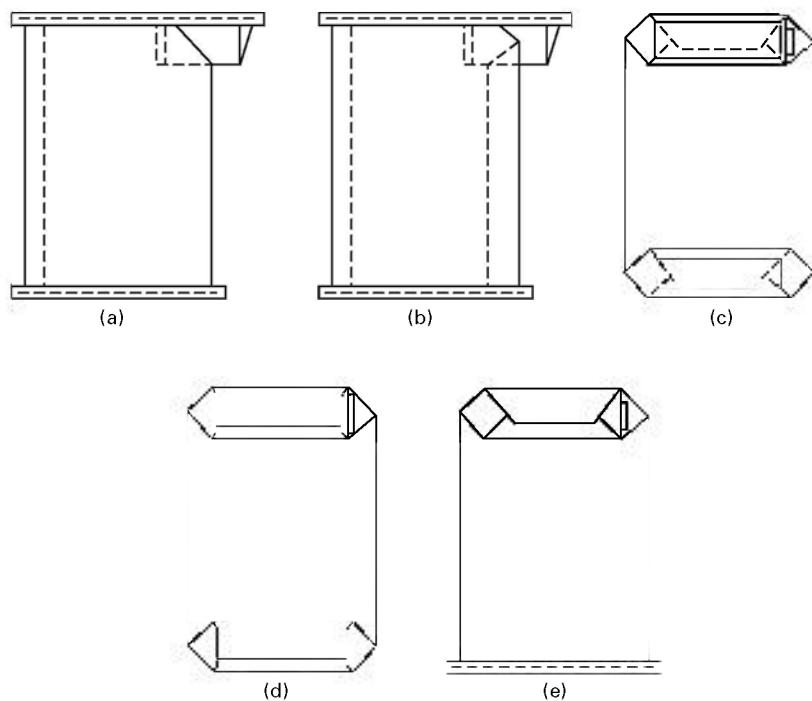
The other main sack design is the valve sack (Fig. 10.35). Typical designs are sewn flat (a); sewn gusseted (b); pasted, flush cut, flat (c); pasted, stepped end flat (d); pasted and sewn, flat (e). During manufacture, one end of a valve sack is completely sealed while the other has a filling spout or valve built in. Valves can be internal (see c, d and e in Fig. 10.35) and can be constructed of plain paper, polymer coated paper, or a layer of polyethylene film. During the filling operation the valve is located on the filling nozzle and the product dispensed into the sack usually with vibration to speed up the process. Once filling is complete, the valve is closed.

Internal valves without any polymer layer rely solely on the weight of the product to close the pack at the valve end; while this is effective for some purposes, it does not prevent a degree of leakage and possible ingress of contaminants. Also, it is not tamper evident. A more effective closure is achieved by heat sealing, which can, of course, only be carried out when polymer-coated paper or polyethylene film have been used in the valve construction. Sacks with external valves are closed by folding the protruding valve section and tucking it inside the sack, again accompanied by heat sealing if the valve construction allows. The folded section can also be secured by applying a self-adhesive tape or label. Thus external valves provide easier and more secure closing, although they are slightly more difficult to load onto the filling nozzle, especially on high speed filling lines and they use more materials.



10.34 Types of open mouth sack design (source: Kirwan, M.J. (ed.), *Paper and Paperboard Packaging Technology*, Blackwell Publishing Limited, 2005. Reproduced with the permission of John Wiley and Sons Inc.; [www.wiley.com](http://www.wiley.com)).

Valve sacks are used for the packaging of granulated and powdered products such as sugar, plastic pellets and cement. Compared with open mouthed sacks, valve sacks provide a faster means of filling but must be vented to allow the displaced air to flow out as quickly as the product is entering the sack. Some sacks are perforated to allow for this, but recently sack Krafts have been developed with a porosity which allows the air to dissipate through the single-ply sack wall at an acceptable rate. Filled valve sacks are more regular in shape than open mouth sacks and thus are easier to palletise in stable loads.



10.35 Types of valve sack (source: Kirwan, M.J. (ed.), *Paper and Paperboard Packaging Technology*, Blackwell Publishing Limited, 2005. Reproduced with the permission of John Wiley and Sons Inc.; [www.wiley.com](http://www.wiley.com)).

Table 10.5 shows the usual tests that would be carried out on the paper and paper sacks to ensure they meet the required specification. The different standards do not necessarily employ identical test methods and therefore care must be taken to ensure the properties of competitive materials are comparable.

### 10.7.2 Paper bags

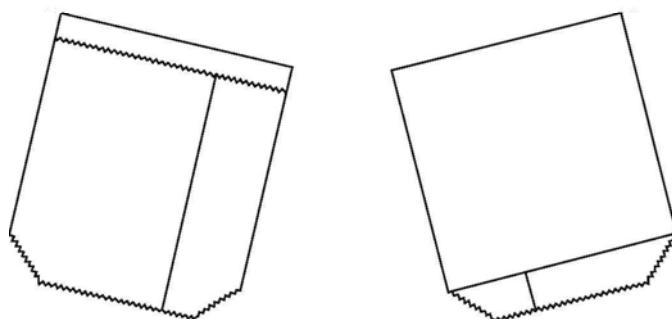
Paper bags cover a wide range of designs and uses, from the grocery sack in the United States to the fine art bags used in the gift trade. The main types of paper bag are:

- flat and satchel
- strip window
- SOS (self opening satchel).

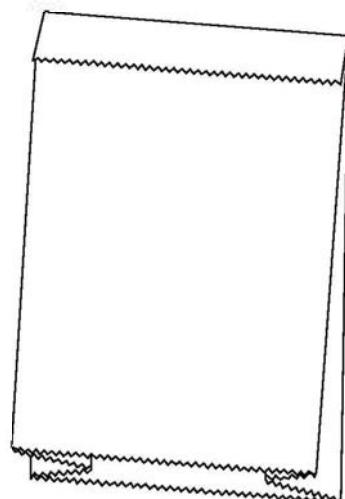
Flat bags are the most basic form. They are two-dimensional and confined almost entirely to point-of-sale use (Fig. 10.36). Satchel bags have gussets which allow the bag, once opened, to become three-dimensional making it much easier than flat bags to handle and fill. Like flat bags, their main use is at point of sale (Figs 10.37 and 10.38). Satchel bags can be supplied with strip windows in one side allowing the product to be seen. These bags were developed for the bread and baguette trade where the window film used is a breathable film, often micro-perforated polypropylene; bio-

Table 10.5 Specifications for multi-wall sacks

Property	ISO	Unit	EN	Scan-P	DIN	Tappi
Grammage	536	g/m <sup>2</sup>		53104	410	
Thickness	534	µm	20534	53105	411	
Density	534	g/cm <sup>3</sup>	20534	53105	411	
Tensile strength	1924	kN/m		67:95	53112/1	494
Stretch	1924	%		67:95	53112/1	494
TEA (tensile energy absorption)	1924	J/m <sup>2</sup>		67:95	–	494
Tear strength	1974	mN	21974	11:96	53128	414
Bursting strength	2758	kPa		24:77	53113/141	403
Bending resistance (static bending force)	2493	mN		29:84	53121	543
Bending stiffness	5629	mN*m		64:90		535
Wet tensile strength	3781 (15 min)	kN/m		20:95	53112/2	456
Surface strength Denison						459
IGT, picking velocity	3782, 3783	mm/s, m/s				
Bendtsen porosity	5636/3	ml/min		60:87		
Roughness Bendtsen	8791/2	ml/min		21:67	53108	538
Roughness Bekk	474	ml/min			53107	479
Roughness PPS, H10 (Parker print surface)	8791	µm				
Roughness Sheffield	8791	ml/min				
Friction	15359	–			53375	815
Cobb 6os (water absorption)	535	g/m <sup>2</sup>	20535	53132	441	
WVTR (water vapour transmission rate)	2528	g/(m <sup>2</sup> *24h)				
Air resistance Gurley	5636/5	s		19:78		460
Moisture	287	%	20287	53103	412	
Ash	2144	%		5:63	54371	413
Opacity	2471	%			53146	519
Brightness	2470	%			53145	452
Lightness L	Cie lab 1964	%				425
Gloss		%				480
pH cold water extract				14:65	53124	435
Measurements of empty sacks				26591-1		
Valve position in paper sacks				26591-1		
Paper sack volume	8281/1					
Dimensional tolerances for paper sacks				28367-1		
Butt drop test for paper sacks	7965/1			27965-1		
Flat drop test for paper sacks	7965/1			27965-1		



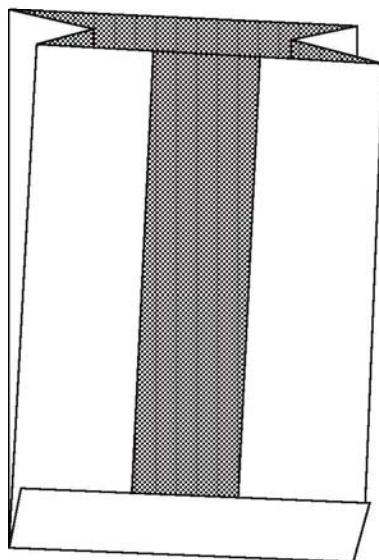
10.36 Flat bag design (source: Kirwan, M.J. (ed.), *Paper and Paperboard Packaging Technology*, Blackwell Publishing Limited, 2005. Reproduced with the permission of John Wiley and Sons Inc.; [www.wiley.com](http://www.wiley.com)).



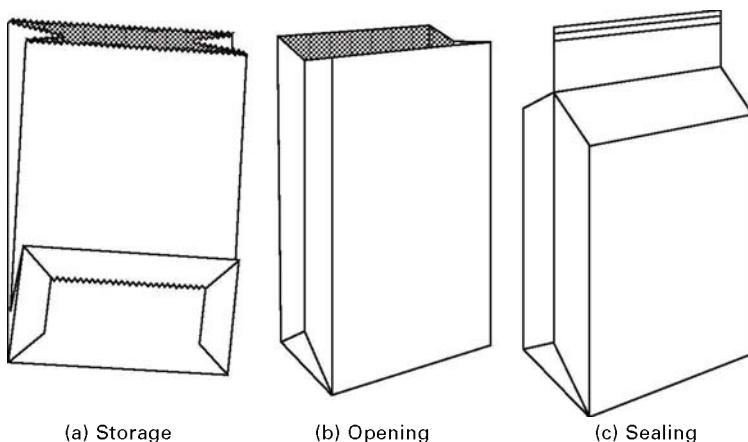
10.37 Satchel (gusseted) bag design (source: Kirwan, M.J. (ed.), *Paper and Paperboard Packaging Technology*, Blackwell Publishing Limited, 2005. Reproduced with the permission of John Wiley and Sons Inc.; [www.wiley.com](http://www.wiley.com)).

compostable polylactic acid (PLA) film is also starting to be used. The breathability ensures that no moisture builds up on the film, thus the bread remains fresh and crisp. Open mouth potato sacks and bags for clothing also utilise the window concept.

The three stages of storage (a), opening (b) and sealing (c) of SOS bags are shown in Fig 10.39. These bags are often constructed from paper laminated to a plastic film, the film providing product protection as well as protecting the paper from deterioration due to the product, for example rotisserie bags for hot chicken. The laminate construction also allows the bags to be closed by heat sealing. SOS bags are used for pre-packaged dry goods and, when handles are applied, as carrier bags for point-of-sale use. The latter may be printed with high quality graphics, offering the brand owner or retail outlet good advertising opportunities.



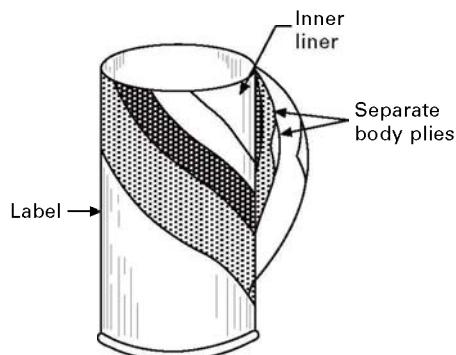
10.38 Satchel bag design with window (source: Kirwan, M.J. (ed.), *Paper and Paperboard Packaging Technology*, Blackwell Publishing Limited, 2005. Reproduced with the permission of John Wiley and Sons Inc.; [www.wiley.com](http://www.wiley.com)).



10.39 Storage (a), opening (b) and sealing (c) of self-opening satchel bags (source: Kirwan, M.J. (ed.), *Paper and Paperboard Packaging Technology*, Blackwell Publishing Limited, 2005. Reproduced with the permission of John Wiley and Sons Inc.; [www.wiley.com](http://www.wiley.com)).

### 10.7.3 Spiral wound containers

Spiral wound composite containers have been in use in packaging for many decades (Fig. 10.40). They consist of three to four plies of paper and paper laminates wound together. The two body plies are composed of recycled Kraft paper, the outer ply is usually a printed paper or paper laminate and the inner ply can be any construction



10.40 Spiral wound container.

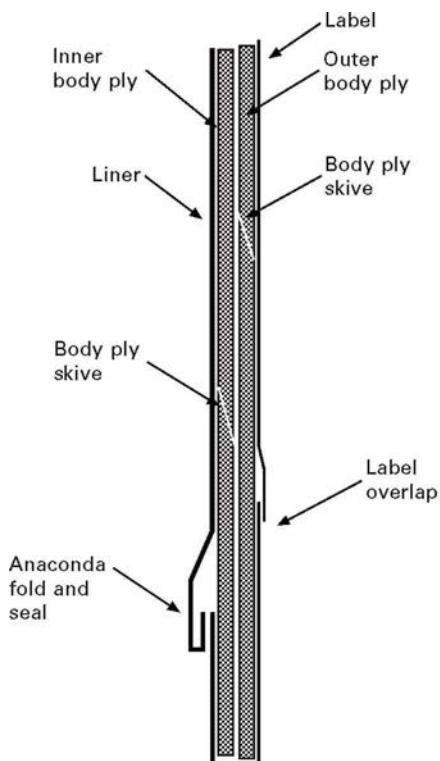
from plastic coated 40 gsm paper to an aluminium/plastic/paper laminate depending on the end use. If aluminium foil is used in the construction of the inner ply, and properly sealed, then paperboard containers can provide sufficient preservation and protection properties to compete in markets traditionally supplied by metal cans.

The plies are wound around a mandrel, each ply being stepped away from the other to ensure the seams do not lie on top of each other. To prevent a ridge forming when the body plies are overlapped, each is individually skived prior to being overlapped and adhered. Skiving is a process by which the edges of the paper are gradually reduced to minimal thickness, so that when they are overlapped the thickness of the overlap corresponds to the thickness of one ply of paper and as a result no ridge is apparent (Fig. 10.41).

The plies are glued together using emulsion adhesives and the inner ply is skived (if too thick to fold) and hemmed to ensure as near hermetic seal as possible is achieved. Skiving in this instance is a process by which the backing paper is gradually taken away from the edges of the underside of the aluminium/plastic layer, to produce a thinner layer, which is then folded through 180° and heat sealed to itself usually by induction sealing. If the inner liner is thin enough, it can be folded over and seamed without needing to skive its backing paper. The seal so formed is called an 'anaconda' seal. If the seal is left as an overlap seal, moisture and gas will penetrate into the inside of the can and attack its contents.

The body of the container can be sealed to the ends in various ways, just four of these being as follows:

- If a hermetic or near hermetic seal is required, metal end pieces can be seamed onto the body in the same way as on metal cans.
- Paper laminated to plastic and/or aluminium foil can be formed into end pieces and heat sealed onto one end of the body section of the can replacing the traditional metal end. A plastic plug or plastic or paperboard over-cap, with or without a heat sealed diaphragm can be applied to the other end of the can, as used on containers for gravy granules.
- A depressed diaphragm can be sealed to the end of the can body and a plastic plug cap can be inserted into the depression, as used on cans of dry fish food pellets.



10.41 Skiving, hemming and 'anaconda' fold.

- The can body end can be pre-curved outwards to accept a heat sealable diaphragm and a plastic overcap applied, locating on the outer curl, as used on Pringles snacks.

#### 10.7.4 Linear forming

Spiral wound containers are normally cylindrical in cross section and deviating from this is difficult and usually requires a second operation, thus increasing cost. Linear forming offers more options because, instead of being wound helically around a mandrel with a circular cross section, they are produced by introducing plies along the axis of a shaped mandrel, thus allowing the final body to replicate the shape of the mandrel. Their construction is similar to spiral wound containers in that they have three to four plies and consist of an inner liner, body plies and an outer label. The closures available are also similar to spiral wound containers.

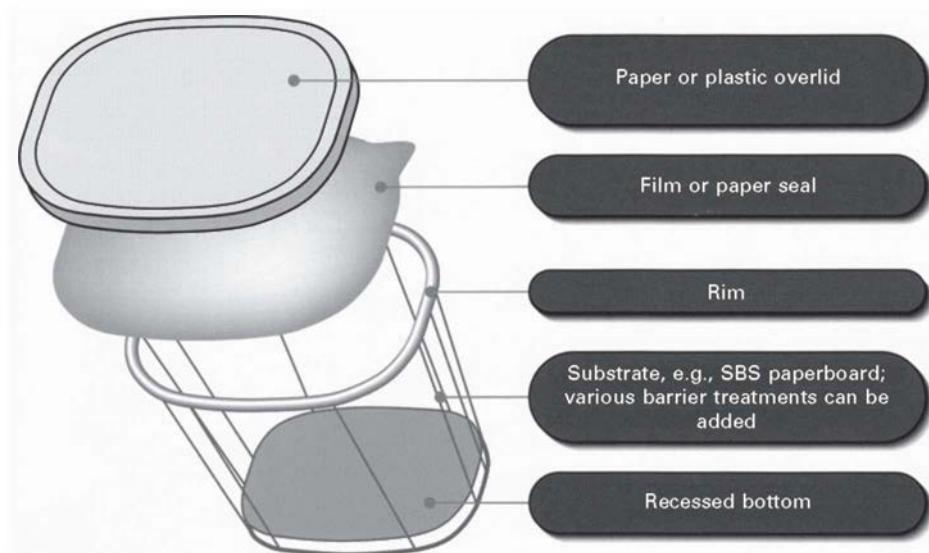
#### 10.7.5 Convolute single wrap containers

Traditionally, convolute can bodies were made by winding a number of plies around a mandrel, to produce a heavy wall container. This has mostly been replaced by a

more efficient method in which a single ply of coated or laminated printed paper is wrapped around a conical or parallel shaped mandrel and the body is heat sealed on the overlap. The single ply of paper is made from chemical pulp and has a heat seal layer on at least the underside. Various alternatives are available. The most common are

- paper/plastic
- plastic/paper/plastic
- plastic/paper/aluminium/plastic.

The rim is curled and a disc is placed in the bottom and secured in place by wrapping the base of the body around it and applying pressure. The container is completed by the addition of a push on closure with or without a heat sealed diaphragm underneath, or simply sealed with a printed diaphragm (Fig. 10.42). In use, many of these containers are packed with dairy products such as butter, yoghurt and ice cream as well as cereals, baking ingredients, snacks and biscuits. They are beneficial to the packer/filler as they can be made in-house, or supplied as a stack, one inside the other. They are not as robust as the spiral or linear formed containers and therefore often require additional secondary packaging for protection against the hazards of distribution. The body seal is occasionally skived and hemmed to ensure no leakage of product into the body (wicking).



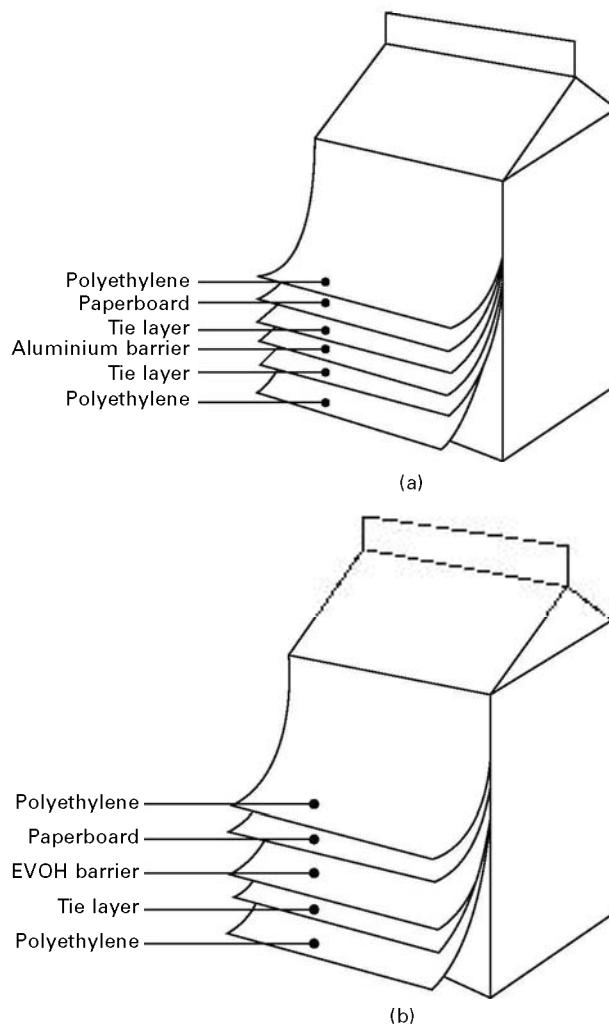
10.42 Convolute can design (source: Paper Machinery Corporation (PMC); [www.papermc.com](http://www.papermc.com)).

#### 10.7.6 Liquid packaging cartons

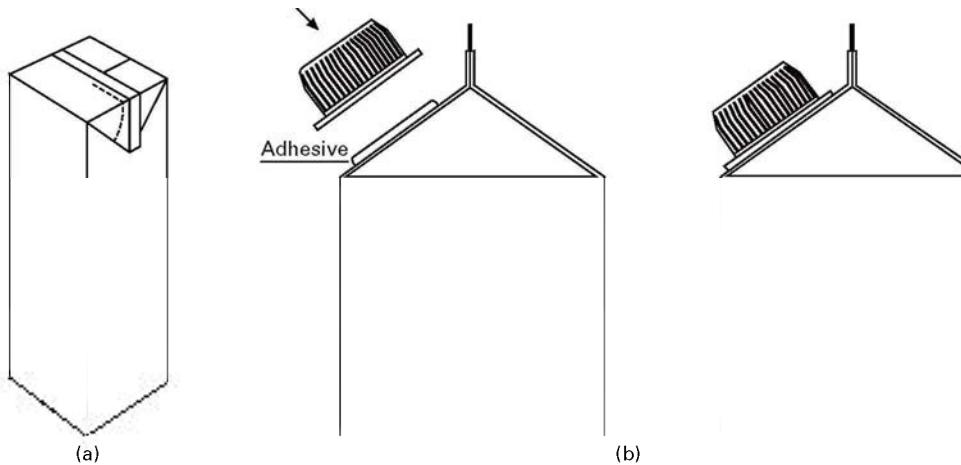
The type of paper or paperboard (210–250 gsm) used for these packs is the same stock as for single-layer, pre-printed, convolute wound tubes. Multilayer virgin bleached

sulphite or CTMP fibre is used due to its excellent strength and/or whiteness. The polymer layer on the outside prevents condensation absorbing into the paper and the polymer on the inside protects the packaging from the product and vice versa (10.43(a)). The whole of the plastic is applied at a coat weight as high as 40 gsm to ensure an integral heat seal. For liquids prone to oxidation, such as long life milk, aluminium foil or EVOH (ethylene vinyl alcohol) are incorporated in the laminate (10.43(b)).

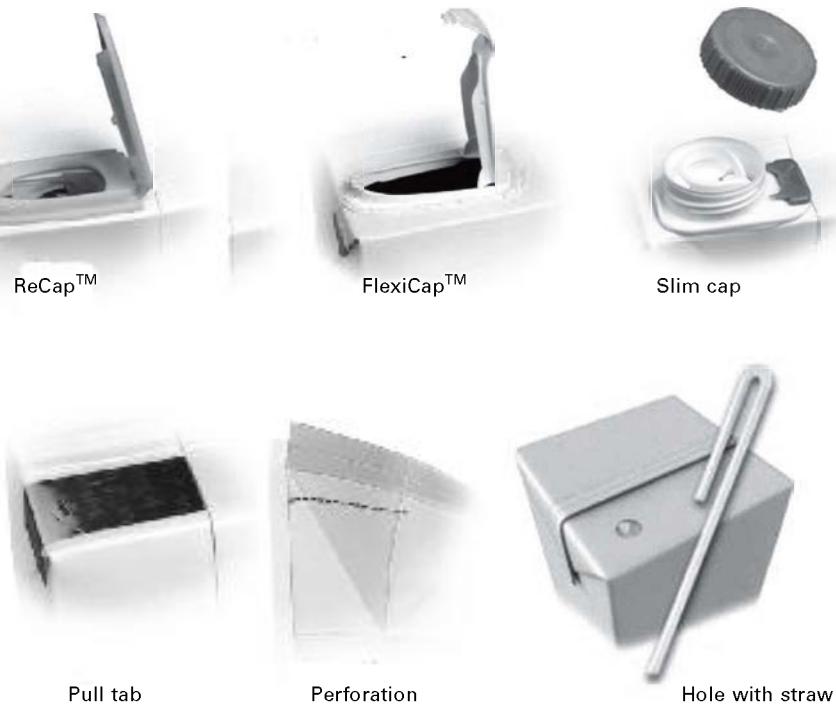
Liquid packaging cartons come in two basic shapes: brick and with a gable top (Fig. 10.44). Openability has been strongly criticised by consumers and features such as plastic pour spouts and more convenient shapes have been added to provide convenience in use (Fig. 10.45). The brick shaped containers are produced by vertical



10.43 Laminates used for liquid packaging cartons: (a) standard and (b) incorporating EVOH.



10.44 Standard brick design (a) and standard gable design (b) incorporating screw top.



10.45 Tetra Pak closure designs (courtesy of Tetra Pak; [www.tetrapak.com](http://www.tetrapak.com)).

form seal technology (see Chapter 20) from a reel of printed laminated paper stock. The gable top containers are printed, cut, creased and heat sealed along the glue flap, similar to a folding carton (see later in the chapter).

## 10.8 Conversion processes for paperboard (>250 gsm)

The packaging formats made from paperboard discussed in this section are:

- folding cartons, multipacks and trays
- rigid boxes
- pressed paperboard trays
- blister cards and Euroslot multipacks.

### 10.8.1 Folding cartons, multipacks and trays

Cartons can be defined generally as small to medium sized containers made from paperboard or in some instances paper (< 250 gsm) or plastic (toothpaste and some cosmetics cartons, for example), although there is confusion in the packaging industry about the term 'carton'. For example, the so-called egg carton is not a carton at all but a container made from moulded pulp specifically to hold eggs. This section covers folding cartons made from paperboard only, and not 'cartons' made from plastic or corrugated material. Cartons are used for their protective and aesthetic properties, providing a very cost effective means of packing products in a sustainable, recyclable material providing excellent graphics and presentation on shelf. They are, however, restricted in their preservation properties, as they possess poor gas and moisture vapour barrier properties, due mainly to the materials used and the integrity of the seal. Grades of paperboard are selected based on the product that is going to be packed, the machinery requirements to pack the product into the carton, the demands of the supply chain, including the retailer and the consumer, and last but by no means least, the cost and environmental considerations.

The top and reverse side of paperboards may be coated with mineral or artificial white pigments as described in paper and paperboard manufacture. All paperboard grades can also be treated with fluorocarbons to give grease resistance (though this process is declining due to fears of taint) or coated/laminated with wax (many countries have eliminated or greatly reduced the use of wax as it hinders recycling), plastic films, water-based barrier coatings and aluminium foil to provide gas, moisture, grease, water barrier and heat sealability, depending on the combination used. The quality of barrier of the finished carton is dependent more on the seal integrity of the carton than on the barrier properties of the materials used. Liquid packaging cartons are either skived and hemmed on the inside vertical seal or the seal is overlain with a plastic membrane to prevent moisture seeping or gas penetrating into the paper (in the same way as for spiral and convolute containers).

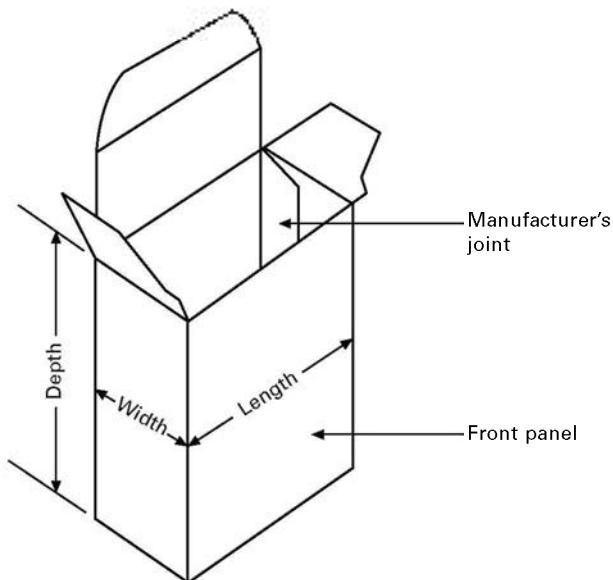
#### *Carton styles*

European and US folding carton styles are classified by the European Carton Manufacturers Association (ECMA) and its US equivalent ACMA. The basic guidelines are as follows:

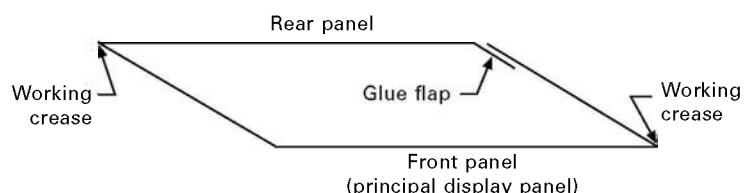
- The glue flap should never be showing on the front face of a carton. This is an aesthetic requirement as the edge of the board would be exposed when the carton

is displayed and this bare edge would detract from the quality of the graphic design (Fig. 10.46).

- The glue flap should not be incorporated with the working creases. When cartons are erected from the flat it is important that the carton opens squarely; if the glue flap is incorporated in the working crease the carton will have a higher resistance to opening (Fig. 10.47).
- Glued cartons should be packed in the transit pack (usually a tray, sleeve or case, shrink wrapped or not) on end with the glue flap at the base. This ensures minimal risk of setting of the creases, which would make the cartons difficult to open as the stiffness of the board could be less than the force required to open the creases, resulting in the carton bending rather than opening. This would result in lost time and wastage on the packing line.
- Unglued cartons should be supplied packed flat, directly on the pallet with layer pads between each layer.
- The grain direction of the fibres in the board should always be at a 90° angle to the major creases. This is very important for consistent crease performance and minimal bowing of the carton. It is important to specify grain direction,



10.46 Folding carton design: length and width determine the location of the opening.



10.47 Folding carton design: relationship between glue flaps and working creases.

especially when using two different suppliers because, depending on the size of printing press used, it may be possible to get an extra carton from a given sheet size by reversing the print in relation to the grain. Although seen initially as a cost saving, this could mean increased costs at the packer/filler and distribution stages (Fig. 10.48).

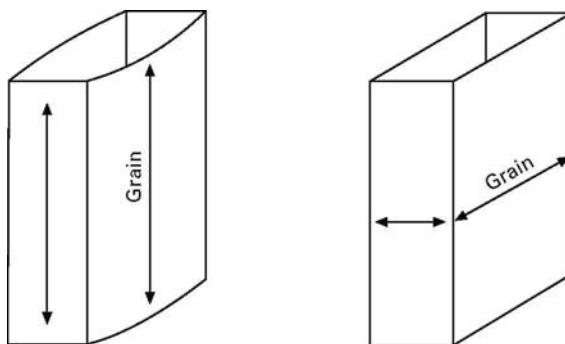
- Carton dimensions should, follow a common industry pattern (see Fig 10.46).
  - they should be given in the order length, width and depth (these are often termed width, depth, height)
  - length and width should define the carton opening
  - depth should be the perpendicular distance between the openings, which is important as the distance between the top and bottom creases on the front panel of the carton are longer than those between the top and bottom of the side panel, by the approximate thickness of the paperboard. This is important to prevent resistance of the outer flaps to folding.
  - measurement should be from centre of crease to centre of crease.

However, different markets use different nomenclature, and places to measure; so it is always advisable to produce a drawing with the actual dimensions marked on it to prevent any confusion (Fig. 10.49).

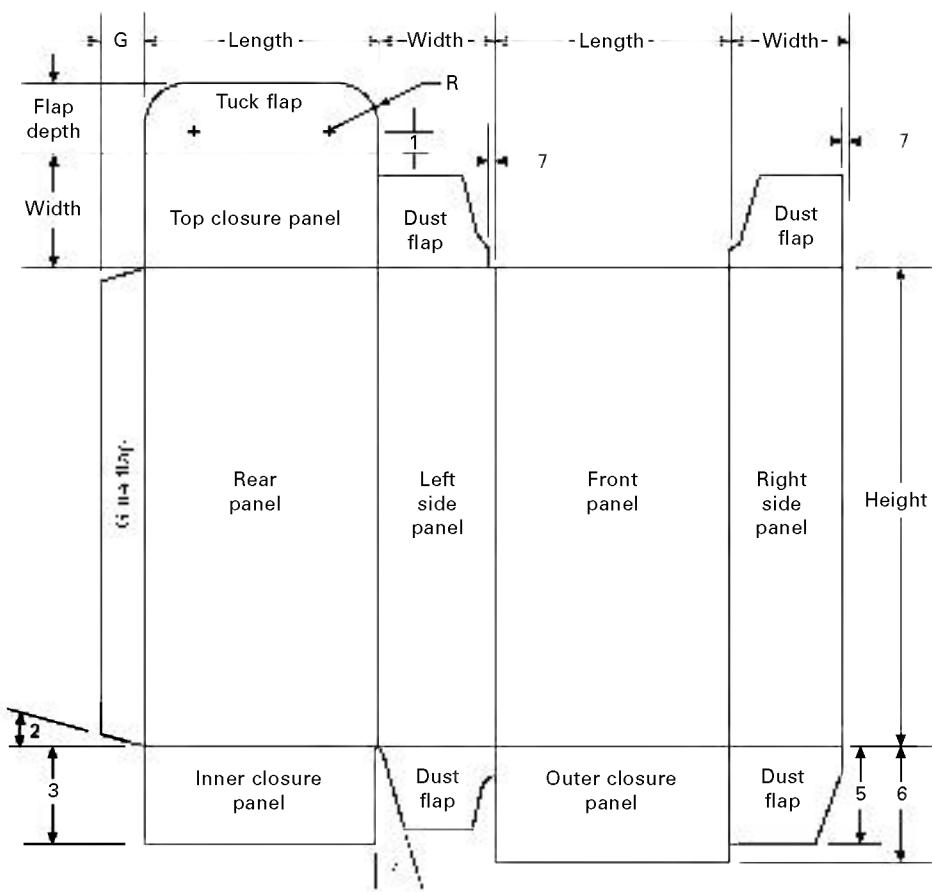
Some common carton styles are:

- end load cartons
- top load cartons

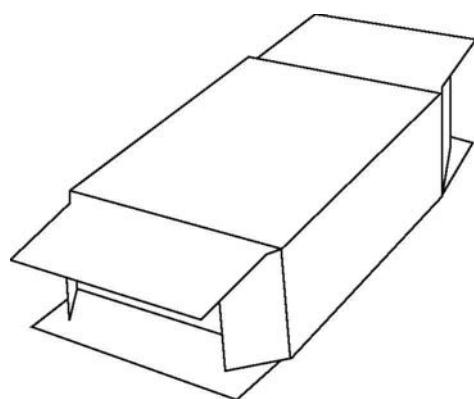
End load cartons are designed to be filled horizontally, e.g. bag-in-box cereal carton, or vertically, e.g. direct fill oats carton (Figs 10.50 and 10.51). They consist of four panels, front, rear, left side and right side panels, glued at the side seam. This is a small flap attached either to the rear or side panel and known as the glue flap. The top and bottom flaps can be glued with hot melt or water-based adhesive, or a tuck flap can be incorporated in the design for mechanically closing and opening (see Fig. 10.52). The left diagram shows a reverse tuck carton and the right an aeroplane tuck. The aeroplane tuck style uses more paperboard than the reverse tuck style, but some consider it aesthetically more pleasing (Fig. 10.53). A cut is often made at the



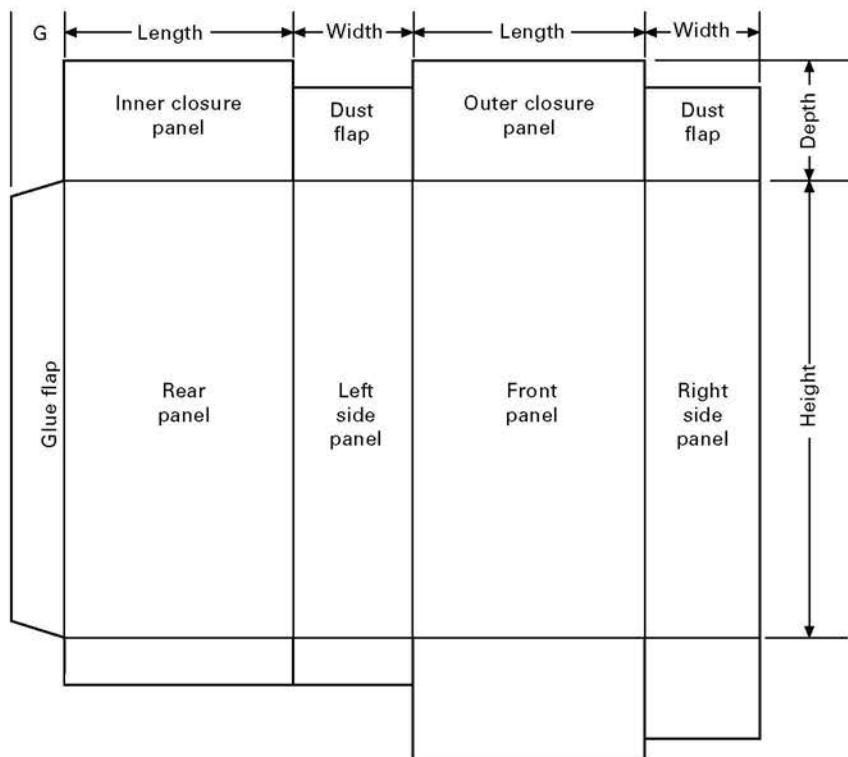
10.48 Folding carton design: carton grain direction should run at a 90° angle to the major creases to ensure maximum carton stiffness.



10.49 Folding carton design: diagram showing dimensions (in this case a tube-style carton with a friction tuck top and a full overlap bottom closure).



10.50 End load carton (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).



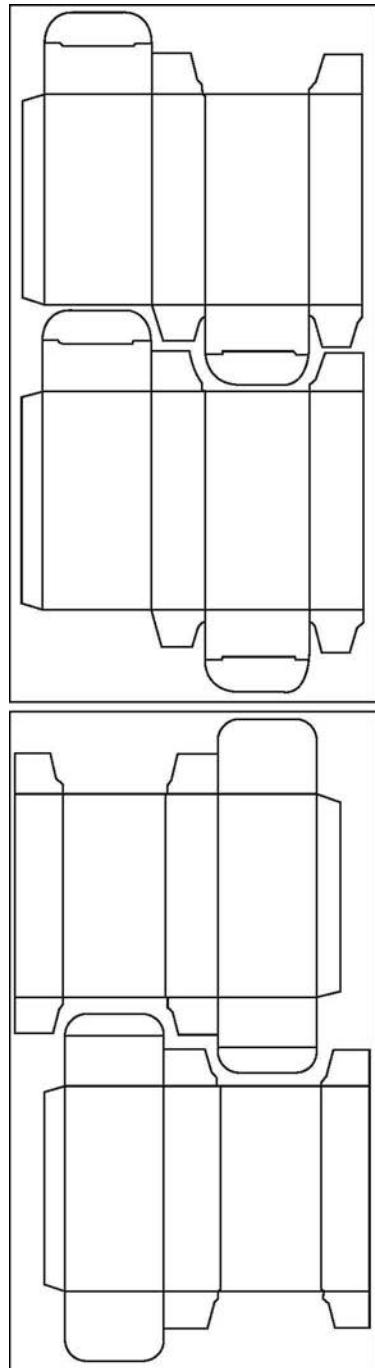
10.51 End load carton: diagram showing basic design.

ends of the flap crease which creates a mechanical lock with the minor flaps helping to prevent the carton opening in transit (Fig. 10.54).

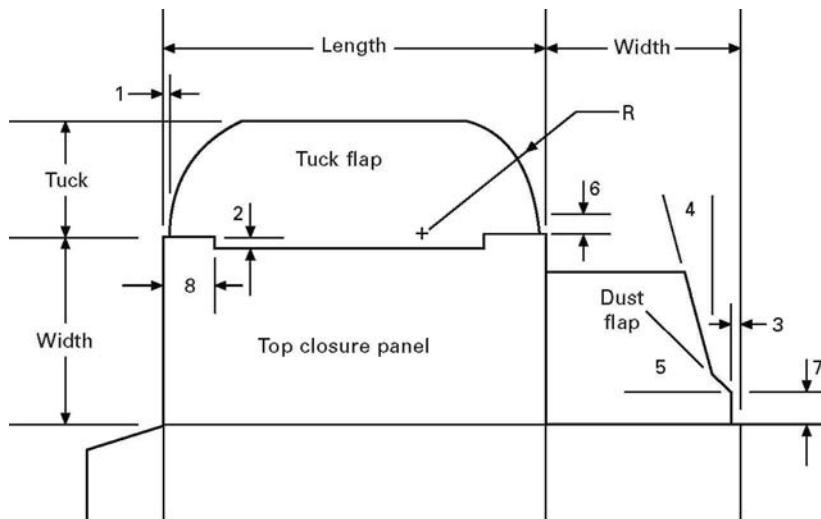
The top load carton is supplied to the packer/filler as a flat blank. It is formed through a die and the side panels are mechanically locked or glued, normally by hot melt adhesive; the product is then filled through the large top aperture and the lid is closed. The lid design can either be a tuck flap as in the diagram, or the flap can be glued to the carton. There is a variety of mechanically locked and glued cartons and trays made in this way (Fig. 10.55). This type of tray (locked or glued) is used to collate cartons prior to shrink wrapping for delivery to the customer. The lock tab version allows for hand assembly on the production line (Fig. 10.56).

The tapered style means that they can be stacked, one inside the other (with the lid up), saving space and ensuring they are ready and open to enable speedy packing of goods at the counter (Fig. 10.57). Plastic coated paperboard can be formed into a heat-sealed web-cornered tray with horizontal flanges which will heat seal to a plastic or plastic coated paperboard lid. This style of tray can be filled with product, the lid sealed on and the whole pack frozen, ready for distribution.

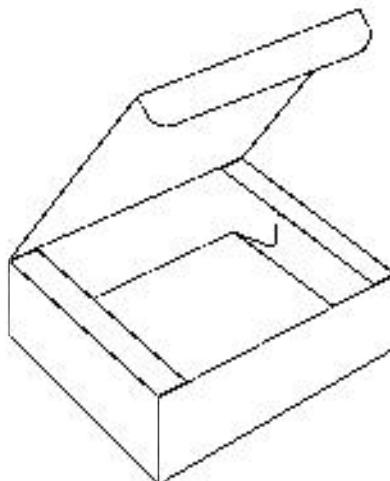
Another style of top load carton, which can be supplied ready glued and folded is shown in Fig. 10.58. A special four or six point gluing procedure with extra diagonal creases allows for these cartons to be laid flat when supplied, negating the need for



10.52 End load carton: reverse tuck (left) and aeroplane tuck (right).



10.53 End load carton: aeroplane tuck design.

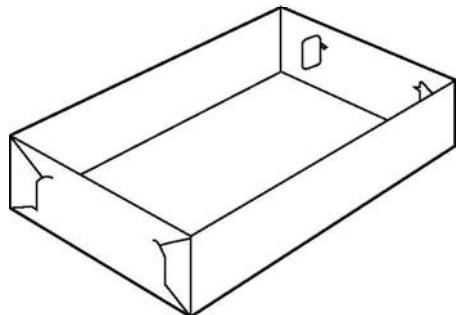


10.54 End load carton: locking mechanism (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).

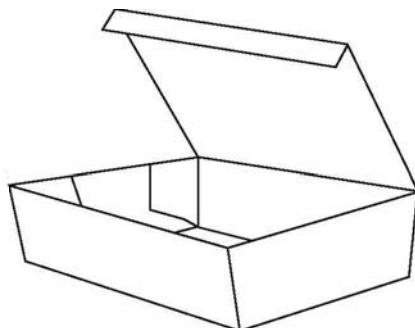
any machine erection and gluing at the customer (e.g. the cake shop). This style of carton often includes a clear window patch.

Cartons are also used to make multi-packs (Fig. 10.59). The board is either a special Kraft board with high water resistance and good wet tear strength or a specially treated recycled board to protect it from moisture and water penetration. These boards are commonly referred to as carrier boards.

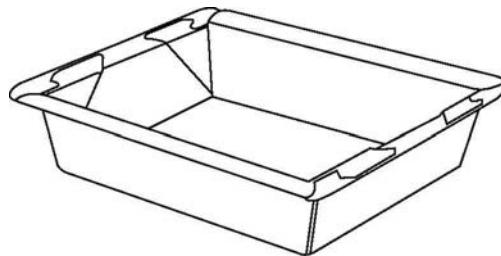
Many other designs and styles are available but too numerous to discuss in this chapter. See Section 10.9 for additional sources of information.



10.55 Top load carton with locked corners (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).



10.56 Top load carton: lock tab design (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).



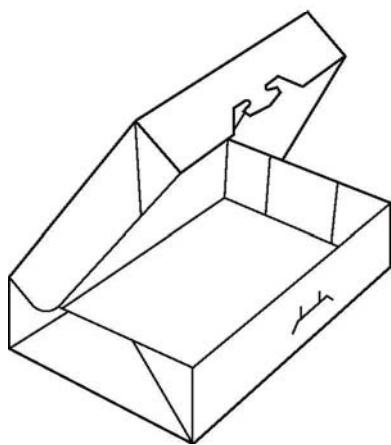
10.57 Top load carton: heat-sealed, web-cornered, tapered tray design (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).

#### *Carton making*

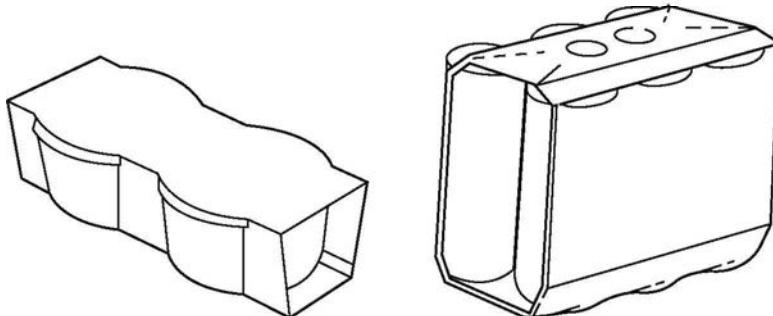
The carton-making process is varied, but there are some common steps; these are:

- printing
- cutting and creasing
- window patching
- gluing.

Prior to printing, the paperboard as received is conditioned, either in the warehouse or by the side of the printing press, for 72 h. This is to ensure the material is consistent,



10.58 Top load carton: six-corner, glued, folded design (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).



10.59 Top load carton: multi-pack for dairy packs (left) and carbonated drinks (right) (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).

especially with respect to moisture content. If it is not, this will affect the print quality. Other areas which may affect print quality relate to the reeled or sheeted board. Checks must be made for cleanliness, especially on the edges, as slitting and cutting dust can transfer to the surface of the substrate creating imperfections on the printed surface. (See Chapter 18 for more detail.)

As the paperboard passes through all the printing presses, it is bent by the tension and feed rolls. This will break some of the fibres, reducing the stiffness and strength of the board and therefore the resulting carton. Mechanical fibre is more susceptible to this than chemical fibre as it is shorter in length and more brittle.

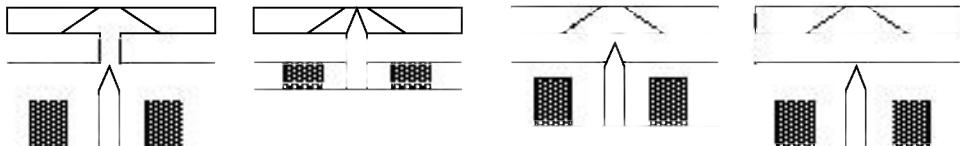
The main three print methods are: offset lithography, which is normally sheet fed, and gravure and flexography, which are normally reel fed. The relationship of the direction of print to fibre orientation within the sheet is very important as discussed earlier. The tolerances and print panels need to be matched to those of the cut and crease die (forme). Failure to do so will result in the carton not being cut and creased in line with the printed design resulting in misregister of print to structural design.

Cutting and creasing is carried out using a flat die for sheet-fed materials or a

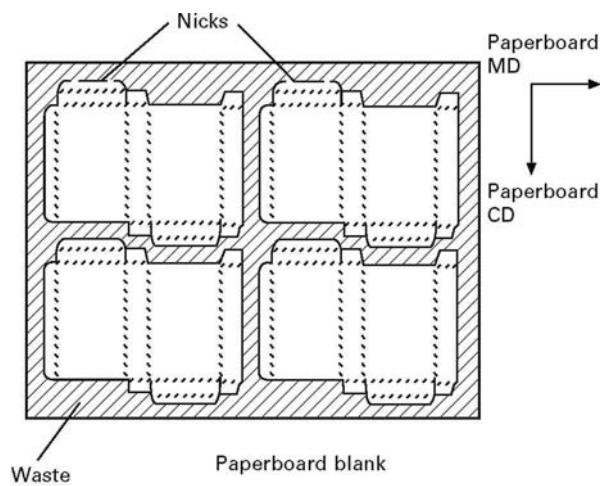
rotary die for reel-fed materials (Fig. 10.60). The cutting and creasing operation (or box cutting as it is known) is as important as the print operation. If the cartons are not cut and creased correctly, their performance will be impaired during the following stages of conversion, filling and distribution. Cartons are cut and creased using a forme. To enable the cutting and creasing operation to be controlled, a counter plate is placed on the base of the press, exactly in line with the forme.

The forme is made from plywood, with steel cutting knives and creasing rules inserted into grooves which are commonly cut using a laser for high accuracy. Special foam rubber pads are placed at either side of the cutting knives to act as springs which remove the board from the blade after the cutting operation. The cutting knife blades are not continuous but designed in such a way that when the cutting operation is complete, they leave nicks between the individual carton cut-outs. This enables the individual cartons to be held together as if they were one sheet when the waste is stripped away. The nicks are broken at the next stage (Fig. 10.61).

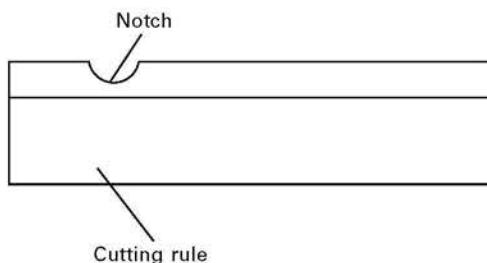
The nick is made by designing notches into the cutting knives. These vary depending on paperboard type and thickness; the stronger the board the narrower the notch (Fig. 10.62). In general, the depth of the notch is made slightly greater than the thickness of the board. The strength requirement of the nick depends on many factors. These include:



10.60 Cutting and creasing forme with make-ready counter (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



10.61 Position of the nicks (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).



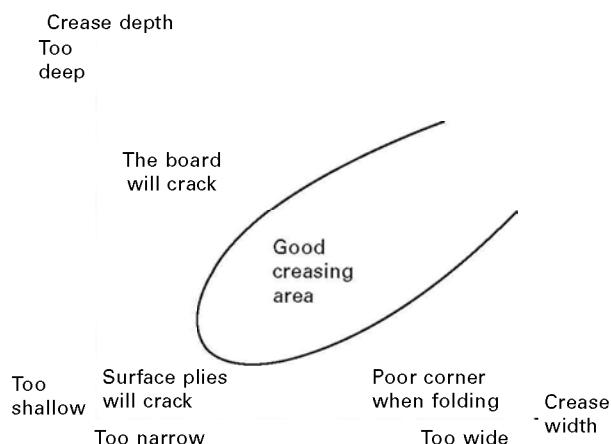
10.62 Die-cutting rule with a notch (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

- grain direction of the paperboard – MD is stronger than CD
- method of making the notches – quality of notch must maintain the integrity of the carton within the sheet without breaking, but must be as small as possible so as not to be seen on the final carton
- strength of the foam rubber to release the board from the knife – the incorrect material could put unnecessary strain on the nick causing it to break prematurely
- dimensions of the nick – normally 0.4–1.0 mm
- how the nicks are arranged is important because if they are not placed evenly across the edge of the carton, undue pressure will be placed on the cut blank resulting in premature breaking of the nicks
- number of nicks per cut edge – more nicks, more strength
- moisture content of the paperboard – as the moisture content increases the strength of the nicks decreases
- quality of fibre used to make the board – the weaker or more inconsistent the fibre, the wider the nick needs to be.

Knife edges blunt over time and need replacing. The speed at which they do so varies with the type of board being cut. Plastic-coated boards often require a specially designed cutting knife. It is uneconomical to use a forme where the knives are blunt or incorrect for the paperboard being cut, as this will result in poor performance on the carton erecting machine and in use.

The other important operation performed by the forme is creasing (Fig. 10.63). Well-formed creases are essential for correctly formed cartons. The quality of crease (and therefore the efficiency of making up cartons on the packaging line) depends on:

- the height and width of the creasing rule with respect to the paperboard being creased – the creasing rule is designed for a narrow range of paperboard thicknesses, and if the length of the rule is too long it will damage the crease area and if too short it will produce an imperfect crease
- the thickness of the make-ready (see below) – if the make-ready is too thin the crease has no room to form properly
- the width of the make-ready groove in relationship to the thickness of the creasing rule – if the make-ready groove is too narrow the crease is likely to form too tightly; if too wide the crease forming operation is not tightly controlled



10.63 Crease depth and width (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

- the accuracy and hardness of the make-ready is critical otherwise the crease will be poorly formed, either through distortion of the make-ready or inaccuracy of the crease
- the pressure of the die cutter – if the pressure is too great, undue forces will be put on the paperboard causing it to split; if the pressure is too weak insufficient pressure is available to form a perfect crease.

The ‘make-ready’ mentioned above refers to the underside of the creasing platen situated beneath the substrate. To ensure an even consistent crease profile, the groove formed as the female form of the creasing rule must have the correct depth and profile and be contained on an even non-deforming metal bed (counter platen). Make-ready matrixes come in three forms:

- self-adhesive metal strips which can be stuck down in place on the counter platen
- plastic (polyester) channel (pre-made) of fixed width and depth
- phenolic resin-impregnated paper/fabric which is pre-etched to match the creasing forme.

The first option is often used for short runs, but relies heavily on the machine operator for accurate placement. The third option is used for complicated designs and long-run work, while the middle option is used for either long or short runs.

Independent of which make-ready is used, they both require the operator to ensure the surface is absolutely even. This is achieved by using specially calibrated self-adhesive tape placed under the low point of the counter to ensure complete overall flatness. This is important because when the forme comes into contact with the substrate and pushes the paperboard into the female form of the counter to make the crease, uneven pressure will be applied if all is not completely flat. This will result in inconsistent creasing which may not show up until late in the converting

or packing operation. To form an efficient crease it is necessary to use a multi-ply paperboard.

Once the make-ready and forme are in place, the cutting and creasing operation can take place. The forme is brought down in a rocking motion onto the sheet of paperboard (print side upwards). The creasing rules push the board evenly into the make-ready matrix and a crease is formed. The waste material from the cutting and creasing operation is removed at the next stage, often using pre-set rods to push it out. The waste is then sent to the baler to be compressed ready for recycling. The remaining cartons, held together with nicks, are palletised awaiting the next process.

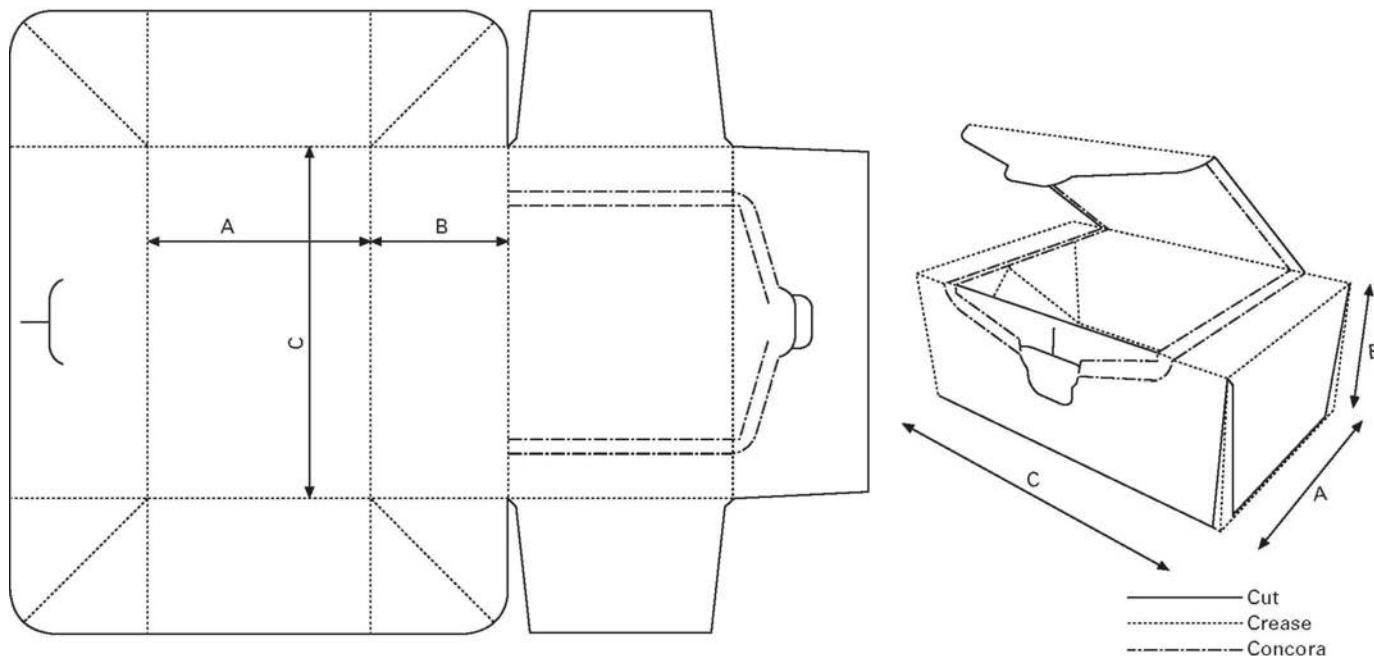
Where the printed paperboard is in reel form, rather than flat sheets, it is die cut using two sets of profiled metal cylinders; one set for cutting and one for creasing. The cutting cylinders consist of one roll with metal cut away to allow the knife profile to be developed and a second, plain roll to allow for kiss contact of the knives with its surface. Poor setting up of the two rolls will result in the knives blunting, producing inferior cut cartons. The creasing rolls are more complicated as the backup roll mirrors the other profiled in design but the crease area is cut away rather than raised. Due to the high cost of this method of rotary die cutting, simpler and less expensive methods have been developed.

At the cutting and creasing stage, opening features, embossing and cut outs can be included. There are many styles of opening feature, with the two most common being the 'zipper' and the 'concora'. The zipper is produced by cutting a series of tram line perforations through the board, which allow the carton to be zipped open at the consumer's convenience. The concora method is more sophisticated and does not pierce the paperboard, but makes a stepped parallel double half cut (60%) from either side of the paperboard (Fig. 10.64). The outer two cuts are wider than the inner two. When the carton is opened the plies part where cut, resulting in a clean tear. It can be used to form a pouring spout, for example, which can be reclosed using the remaining half cut area to act as a seal for the outer. Concora can only be used on multi-ply paperboard.

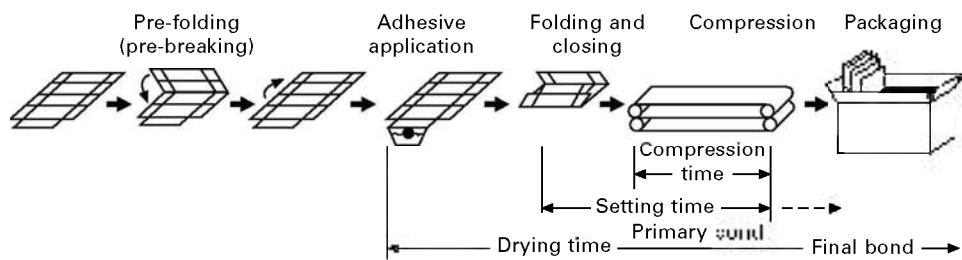
Once the cutting and creasing operations have been completed, the cartons can, if required, be window patched. Adhesive is applied to an area around the window, far enough away from the edge so that the adhesive will not spread into the window but close enough to produce a secure seal. The clear window material is then put in place and pressure is applied to the glued area until adhesion is achieved. Water-based emulsions are the preferred choice of adhesives.

Most end load cartons are pre-glued prior to delivering to the packer/filler (Fig. 10.65). This is a high-speed operation, briefly described as follows:

- Flat cartons are accurately fed into the gluer.
- Working creases are pre-broken by folding through 160°.
- For difficult substrates, the surface to be glued is broken to allow for better adhesion.
- Glue is applied to one of the two surfaces to be glued – often coloured pink or blue so it can be seen to have been applied.



10.64 Carton with concora opening (source: Alexir Packaging; [www.alexir.co.uk](http://www.alexir.co.uk)).



10.65 Glueing operation (courtesy of Iggesund Paperboard; [www.iggesund.com](http://www.iggesund.com)).

- The other surface is brought into contact with the glue.
- Pressure is applied and the bond held until the glue is set.

Once set, the cartons are inspected, tested, packed on their glued creases, labelled and put in storage awaiting despatch to the customer.

The normal quality checks carried out on a carton would be:

- graphics and text to agreed specification – see Chapter 18
- coefficient of friction – see Section 10.6.3
- dimensions – dimensional accuracy is very important as without it the graphic and dimensional designs cannot be matched, nor will the final package be dimensionally controlled; dimensions are usually measured with a calibrated steel rule from centre crease to centre crease
- stiffness (MD and CD) – see Section 10.6.3
- moisture content – see Section 10.6.3
- crease bend resistance – see Section 10.6.3
- fibre tear on glue flap – many paper and paperboard packages are glued along the body seam; if this area is not fully adhered the product can force the glued area to fail and spill out of the package
- carton weight – a large variation in the weight of the carton can result in excess product having to be packed into it to enable it to comply with legislation
- carton compression strength – a measure of the force required to permanently deform the package at a given rate of application
- taint and odour – see Section 10.6.3
- direct food contact – all food packaging must comply with current food contact legislation.

The test methods vary depending on country. The tests carried out on the carton are dependent on its end use and not all tests are relevant to every application.

### 10.8.2 Rigid boxes, carded blister and skin packs

Two other uses of paperboard in packaging are also worth mentioning. They are:

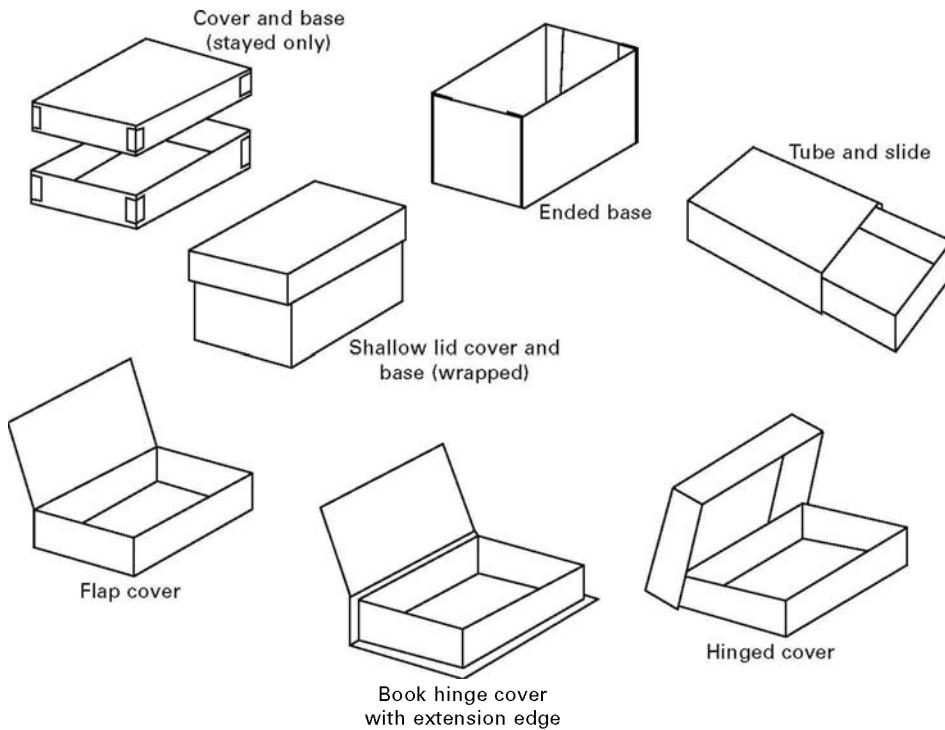
- rigid boxes
- backing cards for blister and skin packs.

Traditionally rigid boxes were the common way of making cartons. Even as late as the 1950s, it was common to find chocolates, hats, shoes and some foodstuffs packed in rigid boxes. Today this style of pack is mainly confined to:

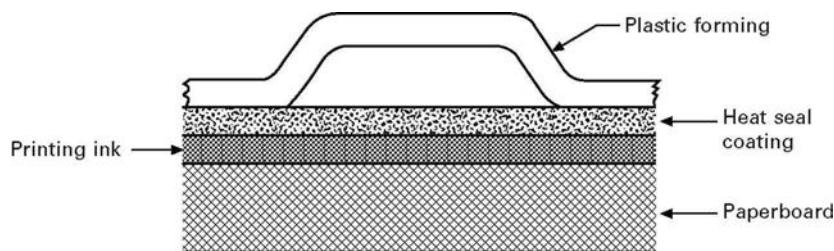
- jewellery and watches
- gifts
- high value perfumes and cosmetics.

Rigid boxes come in many shapes and sizes and are relatively simple, although labour intensive to construct (Fig. 10.66). Blank shapes for the base and lid are cut out of thick, heavyweight, usually recycled board and creased using a scoring wheel. The flaps are then folded along the creases at right angles so they come together to make a tray. The corners are held together (stayed) using wet glued paper tape. A printed cover sheet, usually bleached chemical pulp paper is then wrapped around and glued to the stayed base and lid trays. Other materials can be used, such as leather, fabric, plastic and aluminium foil. Additional sheets can be added to a tray to create a hinged lid. Once dry, the two sections can be inspected, checked for fit and other properties, packed and labelled ready for dispatch to the customer.

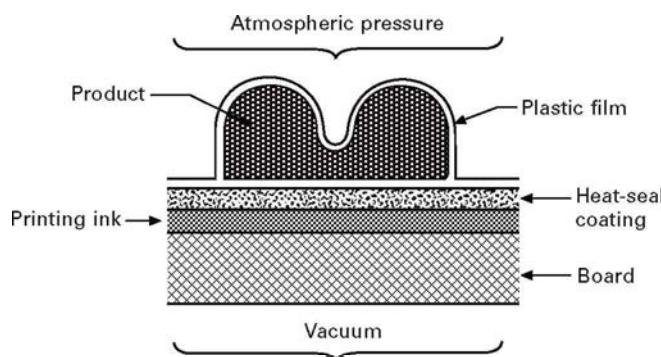
Carded blister and skin packs provide a very cost effective and convenient way of displaying small individual components or mini multi-packs and, although most of the traditional paperboard/plastic blisters or skin packs have disappeared, there are still many examples to be seen on retail display. A blister is a rigid, clear



10.66 Rigid box designs.



10.67 Blister pack construction.



10.68 Carded skin pack construction.

pre-formed thermoformed shape made from a plastic sheet (Fig. 10.67). This blister is often the same shape as the individual packed product, but less defined and larger, to allow for easy placement. The thermoform has a flange around its periphery to enable heat to be applied through the plastic to the low melting point heat seal adhesive coated onto the printed backing card. Environmental considerations have not removed this style of blister as an option just yet; but there is a very powerful lobby driving companies to look for other more environmentally responsible alternatives. The two alternatives that are common in the marketplace are:

- all paperboard pack with special tamper evident features if required
- all plastic pack, with an inserted printed paper for aesthetics and information.

Carded skin packing is similar to blister packing, but in this instance the special grade of transparent plastic skin film is vacuum formed over the product (Fig. 10.68). The paperboard used for this application is printed, coated with a heat seal lacquer and then micro-perforated. This allows for the vacuum to be drawn at the rate required.

### 10.8.3 Moulded pulp trays and boxes

Moulded pulp items are used to stabilise products as well as to protect them from physical damage. Typical packaging formats in moulded pulp are:

- egg boxes
- punnets for soft fruits

- trays for raw meats
- protective sleeves for glass drinks bottles
- corner protection pieces
- fitments for holding small and large components.

The pulp can be made from recycled or virgin fibres, prepared in the same way as for conventional paperboard. Wet strength performance can be improved by the addition of wax, rosin and polymer resins.

There are two basic ways of producing the items, both involving the deposition of wet pulp on a pre-shaped mould, drying to remove the excess water, and removing the formed item from the mould. The pressure process uses hot air under pressure to remove approximately half of the water from the pulp. The alternative method uses vacuum to remove the water, but only up to around 20%. In both processes the remaining water is removed by using heat. The pressure process is usually semi-automatic and therefore the tooling cost is less than for the more automated vacuum method. It also lends itself better to short runs where a wide variety of shapes and sizes are required. Where long runs of standardised items are needed, the vacuum process is preferable.

The moulded pulp packaging can be bonded to plastic films which provides barrier protection, allowing them to be used for trays for fresh produce where the whole will be flow wrapped. Expanded polystyrene packaging is being replaced by moulded pulp, even for large items such as desk top printers and household electrical products.

## 10.9 Sources of further information and advice

For further information on carton styles and designs contact:

- ECMA – European Carton Manufacturers Association: [www.ecma.org](http://www.ecma.org)
- Pro Carton – [www.procarton.com](http://www.procarton.com)
- Iggesund – Paperboard reference manual ([www.iggesund.com](http://www.iggesund.com))
- Billerud – Sack Kraft and Sack manufacture ([www.billerud.com](http://www.billerud.com))
- Korsnäs – Sack Kraft, Carrier Board and Kraft Paperboard for conversion into cartons ([www.korsnas.com](http://www.korsnas.com))
- Kirwan, M. J. (ed.), *Paper and Paperboard Packaging Technology*. Blackwell Publishing, Oxford, 2005.
- PITA – Paper Industry Technical Association ([www.pita.co.uk](http://www.pita.co.uk))
- Soroka, W., Emblem, A. and Emblem, H. (eds), *Fundamentals of Packaging Technology*, IOP, Stamford, 1999.
- Sonoco Products ([www.sonoco.com](http://www.sonoco.com))
- Paper Machinery Corporation ([www.papermc.com](http://www.papermc.com))
- Alexir Packaging ([www.alexir.co.uk](http://www.alexir.co.uk))
- MMP – Mayr Melnhof Packaging ([www.mayr-melnhof.com](http://www.mayr-melnhof.com))
- MMK – Mayr Melnhof Karton ([www.mayr-melnhof.com](http://www.mayr-melnhof.com))
- Tetra Pak ([www.tetrapak.com](http://www.tetrapak.com))
- Elopak ([www.elopak.com](http://www.elopak.com))
- Walki ([www.walki.com](http://www.walki.com))

# 11

## Corrugated board packaging

T. WATKINS, UK

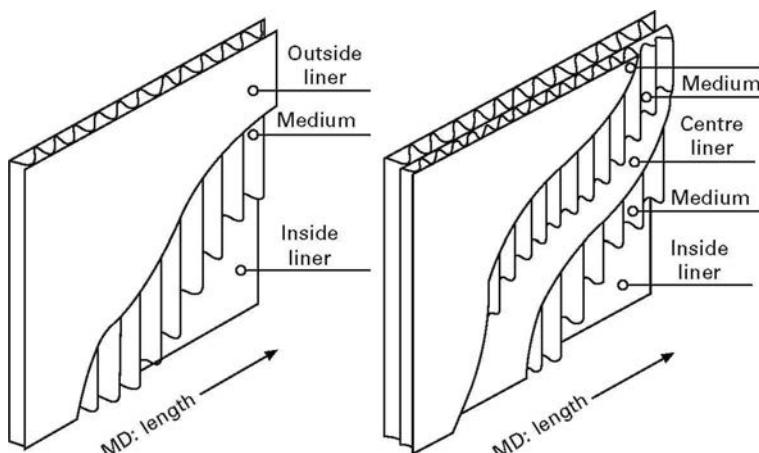
**Abstract:** Corrugated fibreboard is manufactured using papers suitable for flat surfaces (liners) and the corrugated inner structure (fluting medium). This chapter covers the papers and adhesives used in board manufacturing processes and the conversion into packaging and display items. It also covers the types of corrugated board produced, their testing and some basic designs.

**Key words:** liners, fluting and adhesives, corrugator machines, regular slotted and die cut containers together with their decoration and printing, testing methods.

### 11.1 Introduction

Corrugated fibreboard is the most widely used secondary packaging material. It is typically constructed from two facings or liners bonded to a corrugated (fluted) medium. A corrugating machine forms the medium into a fluted pattern and bonds it to the liners using adhesive. Some basic configurations are shown in Fig. 11.1:

- single-wall (one fluted medium with two liner plies): a standard type for most product types
- double-wall (two fluted medium plies and three liner plies) used for heavier or more bulky products such as machinery, large appliances or furniture, or for display stands, or for products which are stored for extended time periods
- triple-wall (three fluted medium plies and four liner plies) used for particularly



11.1 Single-wall (left) and double-wall (right) configurations.

heavy-duty applications, e.g. as a substitute for wooden containers for pallet boxes or bulk bins.

A single faced material is also available, made up of one fluted layer and one liner; this is a flexible material, suitable for general purpose wrapping.

Corrugated fibreboard has been manufactured since the late nineteenth century, with the first patents being filed in the United States in 1871. Much can be seen today that directly relates back to then, but the major shift in corrugator speeds from 1.8 m/min at 1.8 m. to that of 300 m/min at 2.5 m wide, is due to constant refinement and development. The first big step was the introduction of the Stein Hall process in 1937 which used part of the starch adhesive mix bonding the papers to be gelatinised, whilst the remainder was carried as slurry, enabling a much higher proportion of solids to be used (21–23% starch suspended in water). Drying time was reduced, allowing corrugators to run at higher speeds and produce board with minimal warping. Although this process has in the main changed back to a 'single bag' mix, the starch is modified to enable this carrier and slurry action to take place. It is this type of chemical development combined with automatic reel splicing, direct drive shearing knives, precise computer driven gap and temperature control that enabled this increase in manufacturing speed.

Much the same holds true of the conversion process, with a major milestone being the introduction of case making machines capable of printing, creasing, gluing and folding in a single pass. This equipment has in many cases been augmented with the introduction of rotary die-cutting sections, making it possible to perforate and incorporate locks into designs being manufactured with particular application for retail ready packaging (RRP). The majority of integrated plants, i.e. those with their own corrugators, are fully conveyorised and product is only palletised once ready for transport. Full traceability is maintained, from incoming paper stock to finished cases.

In the United Kingdom some 2.1 million tonnes of paper is used to make 4.1 billion square metres of board, which is converted into cases and trays. Market sector usage is around 17% for processed foods, 17% for fresh foods, 9% for beverages and 19% for industrial products, with the remainder being used for a wide range of durable and non-durable products. A significant influence on the industry in recent years is the move to retail ready packs (RRP), where the secondary packaging provides the retailer with a quick and easy method of shelf loading. Another influence is the widespread use of returnable packaging (mainly plastic crates), which has led to a loss of sales in the industry. Returnable packaging is ideal in closed loop distribution systems such as the transport of fresh produce and many other food products from packer-filler to supermarket, where the loss of relatively expensive crates is minimal. However, the growth of internet and mail order sales has the potential to offset some of this loss of sales, because this sector cannot realistically operate in a closed loop. This direct-to-consumer packaging is almost impossible to recover and reuse and hence has a one-way use. Corrugated board has environmental advantages here, given that in excess of 80% of materials are recycled and some 76% of packs are produced from recycled fibres in the UK.

The demand for RRP has come from the retail sector, with the desire to fill shelves at ever-increasing rates. This challenge has led to significant investment and development by the industry, with die-cutting units being introduced to single pass case-making equipment. These specialised packs can be easily transformed from transit cases into attractive and functional on-shelf display units at the retail store and are commercially attractive due to the improved efficiencies of this type of packaging.

## 11.2 Materials for corrugated board

There are three basic components required:

- liner or facing materials
- flute materials
- adhesives.

### 11.2.1 Liner/facing materials

The facings can be made from Kraft paper (named after the chemical pulping process used to manufacture the paper) which has a high proportion of virgin fibres and added recycled papers (known as 'Test' materials). The recycled papers are made from in-process waste and from used cases and trays collected from supermarkets and other outlets. These 'Test' materials owe their name to an obsolete puncture test demanded for railway distribution and are categorised as TL1, TL2 and TL3. The long fibres on the outer ply of TL1 and its highest performance amongst all Test materials mean that it is used as a Kraft substitute, whereas TL2 and TL3 are only distinguished by their short span compression strength (SCT) values and are the most widely used papers. TL3 is the most common with the higher performing TL2 being used in more challenging environments such as frozen food packaging.

Varying amounts of recycled or secondary fibre are used for producing both liners and corrugating medium, a practice which has grown as recycling has increased. Recycled board is made to the same specifications as virgin material, so that stiffness and burst values are similar, although it is slightly thicker to compensate for the weaker recycled fibre (see Chapter 10). Other properties will depend on the source and quality of the fibre. Recycled board typically has a somewhat smoother surface finish (and therefore better printability) and a lower coefficient of friction than virgin Kraft. Recycled board may absorb water significantly faster than Kraft, which could be important when packing wet products such as fish. Whether Test or Kraft, white or brown, corrugated materials can be found performing quite satisfactorily on the wide range of tray, wrap-around and case erecting and packing machines in use.

By using bleached fibre combined with Kraft, a whiter surface providing better graphic presentation can be obtained. If the bleached fibre layer is thin and not uniform, some of the background Kraft shows through, giving it a mottled appearance. Mottled white and Oysterboard are common commercial names used to describe this board. Papers with a thick even layer of bleached fibres have in the main replaced fully bleached white Kraft. The two-ply natural and white Kraft material is used where

high-quality graphics are required and is sometimes enhanced with a clay-coated finish. It is typically used in preprint applications, where the outer layer of material is printed before being made up into corrugated board. This avoids the lined effect obtained when printing on a corrugated surface.

A 'balanced' construction is one where the outer and inner liners have identical weights (or grammages). However, corrugated board can be manufactured using liners of different types and grammages, e.g. using a heavier liner to ensure a better outer surface for printing. Unbalanced constructions tend to have more problems with board warping, but can be appropriate on the grounds of cost and/or functionality. For better printing, the heavier liner should be the outer liner, whereas for better compression strength, the heavier liner should be on the inside.

### 11.2.2 Flute materials

Fluting medium is a one-ply sheet produced from recycled and/or virgin fibres. Where virgin fibres are used, the pulp is prepared using the CTMP pulping process (see Chapter 10), giving a short fibre suitable for corrugating. This is known as semi-chemical fluting and currently represents only a small percentage of fluting used, the majority being made from chemically-enhanced recycled fibres. There is a range of standard flute sizes (Table 11.1):

- A-flute: the largest size
- C-flute: the second largest
- B-flute: the third largest
- E-flute: the fourth largest
- F-flute and other finer flute sizes

Table 11.2 summarises the differences among the main types of flutes.

A-flute is useful for cushion pads, the construction of particularly heavy-duty boxes and the construction of triple-wall board grades where the added thickness is an advantage. However, use of A-flute has been in decline. A-flute's almost 5-mm thickness occupies more space than C-flute and has significantly greater deflection before bearing load when compressed. In theory, A-flute's thicker section should give it the highest top-to-bottom compression strength of the three flutes. This is true under laboratory conditions. However, A-flute has the lowest flat crush resistance (see Table 11.3). This makes A-flute with <127g medium almost impossible to machine

Table 11.1 Standard flute configurations

Flute type	Approx. no. of flutes per metre	Approx. height of flutes (mm)
A	105–125	4.5–4.7
C	120–145	3.5–3.7
B	150–185	2.1–2.9
E	290–320	1.1–1.2
F	400–440	0.7–0.8

Table 11.2 Comparing characteristics of the main flute sizes

Flute height (mm) (ave)	Flute	Flutes per metre (ave)	Stacking strength	Puncture resistance	Cushion	Flat crush	Surface print quality
4.5–4.7	A	110	Best	Good	Best	Poor	Poor
3.5–3.7	C	129	Good	Best	Good	Fair	Fair
2.4–2.6	B	154	Fair	Fair	Fair	Good	Good
1.1–1.2	E	295	Poor	Poor	Poor	Fair	V good
0.7–0.8	F		Poor	Poor	Poor	Poor	Excellent
0.5	N		Poor	Poor	Poor	Poor	Excellent
0.4	G		Poor	Poor	Poor	Poor	Excellent

Table 11.3 Approximate relative flute flat crush values

Medium grammage	Flute		
	A	C	B
127 g	0.70	1.00	1.15
140 g	0.90	1.25	1.45
200 g	1.10	1.50	n.a.

and transport without destroying the flute structure. Engineering studies suggest that A-flute is most efficient when constructed with a 200 g medium.

C-flute has about 10% better stacking strength than the same board weights in B-flute. It is best for applications where the corrugated container must bear some or all of the stacking load. C-flute is sometimes chosen over B-flute for cases that will hold glass bottles, despite C-flute's lower flat crush strength. It is felt that the thicker flute will provide more puncture protection for the glass. Some authorities regard lightweight medium C-flute as having less than minimum acceptable flat crush for shipping applications.

B-flute is used for canned goods or other products where case stacking strength is not required. B-flute's high flat crush strength is an advantage when supporting heavy goods such as bottles or cans. It can also be used to advantage for lighter load applications where high stack strength is not needed, or where the distribution environment is very short. Heavy media cannot be made into the small B-flute. A recent development offering material and space savings over B-flute is R-flute corrugated board. The flutes are smaller and closer together than B-flute, resulting in better printing surface and 20% lower caliper, meaning more board can be shipped per pallet (*Packaging Today*, 3 February 2011).

E-flute and smaller flutes (often known as microflutes) are not generally associated with shipping containers. They are mostly used to replace carton board for heavier or special protective primary packs. E-flute is an excellent choice where the primary container may become an RRP container for some part of its use. There is a range of finer flutes such as F, G, N and T, some specific to certain manufacturers and used when high-quality graphics are required. Gift packs for drinks, etc., is a typical end use, as well as cases for small tools, hardware appliances and home wares.

Double-walled or triple-walled constructions can have a combination of flute types,

perhaps E or B on the outer and B or C flute on the inner, offering a flat surface for printing combined with a load bearing flute on the inner. Triple-wall materials are often the exception to this and have load-bearing C and or A flutes throughout to provide the strength needed for industrial applications such as heavy engine components.

Liners and corrugating medium material can be made to virtually any weight or thickness. However, custom and practice has led to the standardisation of certain traditional grades (see Table 11.4). Finished board is described by component grammage: the mass in grams per square metre. Measurements start from the outside. Corrugated board described as 170/127C/170 would have the following components:

- Outside liner = 170 g
- Medium = 127 g formed to a C-flute
- Inside liner = 170 g

Corrugated board specifications sometimes disregard the fact that paper is a natural product. A given paperboard characteristic can easily vary by 8% or more, and tolerance levels must take this into account.

### 11.2.3 Adhesive selection

Standard corrugated board is made with a starch-based adhesive applied at about 10–14 gsm. Starch loses strength at high moisture levels. However, corrugated board also loses around 50% of its compression strength between 50 and 90% RH, so both need some form of reinforcement or protection in wet conditions. Where higher resistance is needed, starches can be modified by adding various polymers. Water-resistant adhesives are more expensive and are typically used in conjunction with corrugated board that has liners with a membrane or coating to repel water. Cold adhesives, such as polyvinyl acetate (PVA) are normally used to glue several corrugated sheets to form extremely strong materials for heavy duty applications.

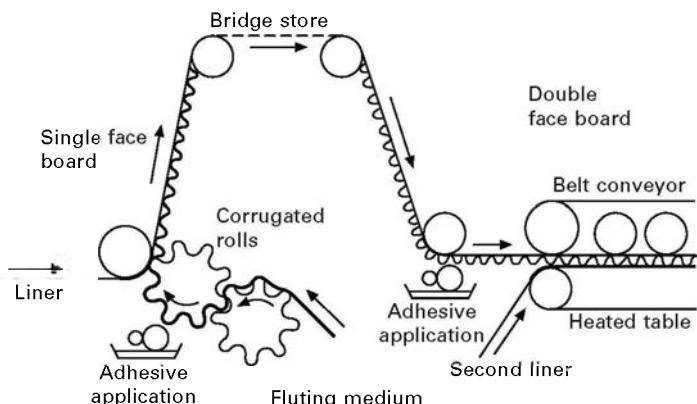
## 11.3 Manufacturing processes for corrugated board

A corrugating machine consists of several steps (see Fig. 11.2). These involve:

- unwinding and conditioning of liners and medium
- corrugation of the medium (to create the flutes)

Table 11.4 The most commonly used grammages for liners and flutings

Kraft/Test	Mottled/White	Fluting
95 g	125 g	90 g
115 g	140 g	100 g
125 g	200 g	127 g
125 g	140 g	
170 g	170 g	
275 g	200 g	
400 g (Kraft only)		



11.2 Corrugating machine.

- bonding the fluted medium to the liners
- drying the finished board
- cutting and scoring the board.

Single-facer stations create the fluted medium and bond it to a single liner or face (usually the inside liner), before passing it on to double backer stations which add the second (outer) liner.

At the beginning of the process, both medium and liner are preconditioned with steam to make them pliable for processing. The medium is fluted by being passed between large rolls with a surface pattern matching the required flute geometry. Older machines used fingers to hold the fluted medium whilst it was being processed, but modern machines use vacuum pressure to hold the medium in place, reducing potential indentations and improving compression strength. Adhesive is then applied to the flute tips. The liner is pressed against the tips, where a combination of heat and pressure bonds the two surfaces together. Typically, greater pressure is used at this stage to ensure a strong bond, resulting in the glue lines potentially showing through. This is why this liner is usually on the inside of the finished case.

The single-faced material, which is still flexible at this point, is sent to a conveyor mechanism known as a 'bridge', where it is draped in an overlapping wave pattern as it travels to the double-backer station. The purpose of the bridge is to separate the single-facer and double-backer stations, allowing for different operating speeds and reel changes. At the double-backer station, adhesive is applied to the flute tips on the other side of the medium and the outer liner is glued on. Corrugators normally have more than one single facer unit, which allows additional plies to be combined at the double backer to create double-or triple-wall boards.

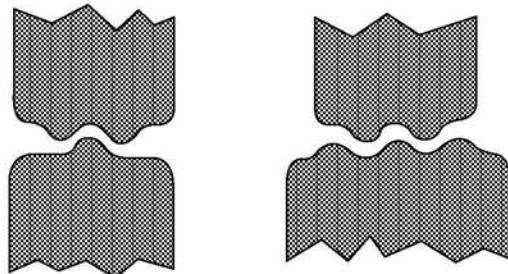
The fully assembled corrugated board with liners on both sides is now stiff. It is passed between two long flat belts for final heat setting and cooling. The edges are then trimmed, and the finished board is slit to widths and cut to lengths as required. At the same time as slitting to the correct width, the machine will also score along the planned flaps for folding. The finished sheets are then stacked ready for assembly.

There is a range of scoring patterns, depending on the container design, starting

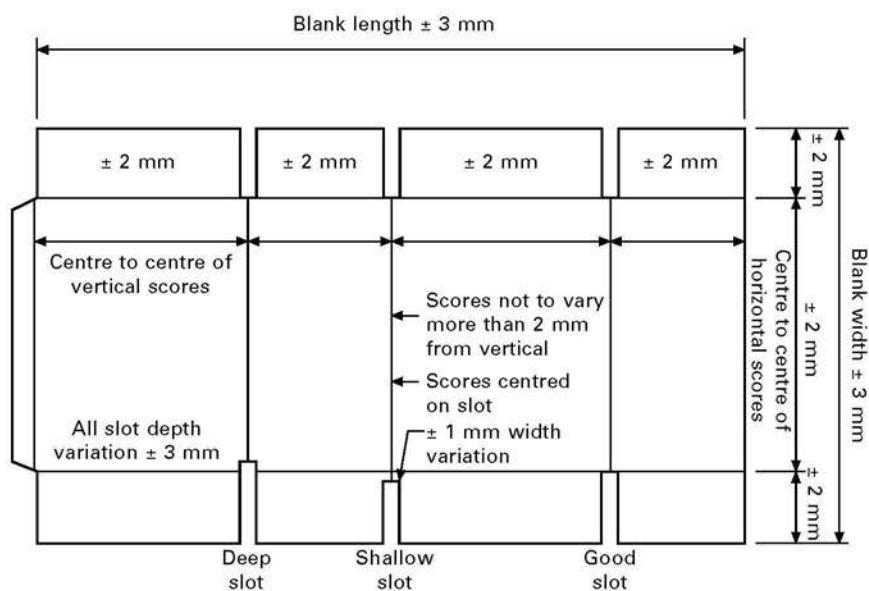
with scores along the top and bottom flaps (the reverse scores). Three-point or off-set point-to-point scores are used where the case flaps will be folded in one direction to close the container. Where flaps need to be first bent outwards, these bend profiles may produce an uneven break when heavy materials are used. In such instances a five-point score is preferred (see Fig. 11.3).

The resulting joint can be glued, taped, stapled or stitched. Gluing is a relatively simple and fast operation which offers a strong joint. It is the most common joining technique. Double-gluing can be used to reinforce corners. The data in Figs 11.4–11.8 provide typical scored sheet and manufacturer's glue joint tolerances for B and C-flute single-wall cases.

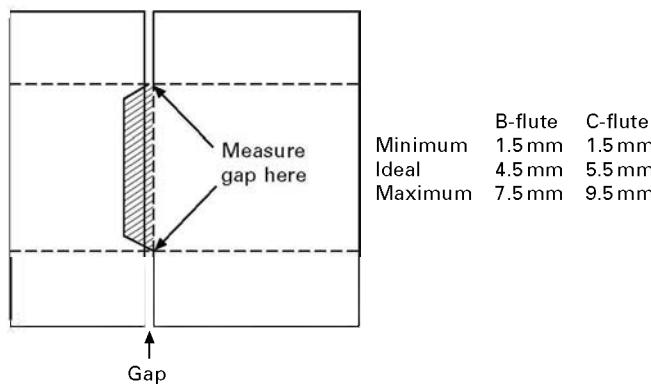
Taping, stapling or stitching are slower, semi-automatic operations. Wire stitching is commonly used on triple-wall constructions and where treatments such as waxing prohibit normal gluing. Taping is used for oversized cases not able to be put through



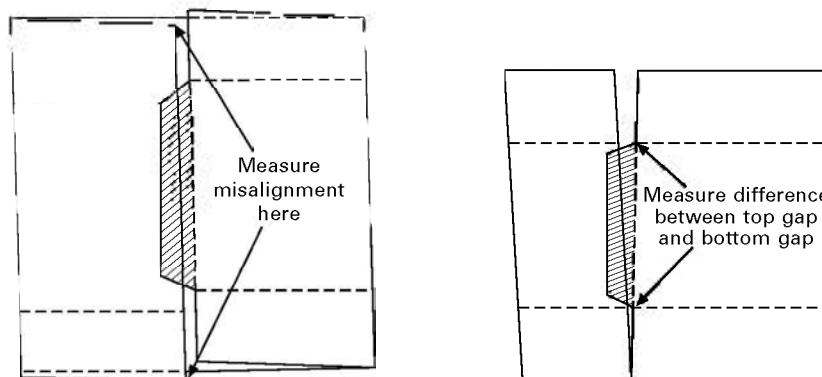
11.3 Profiles of three-point (left) and five-point (right) scoring wheels.



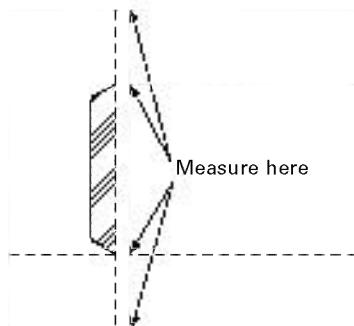
11.4 Typical scored and slotted sheet tolerances for B- and C-flute single-wall cases.



11.5 Gap tolerances for B- and C-flute single-wall cases.



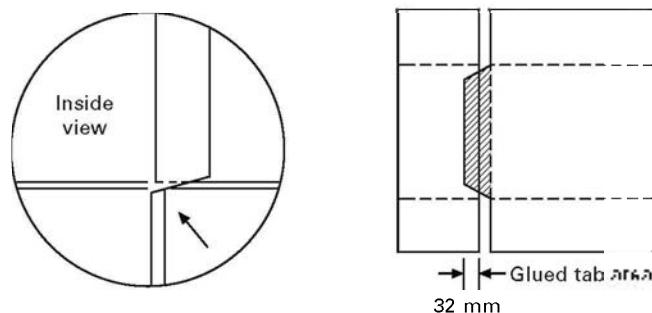
11.6 Gap tolerances for out-of-square and fishtail (U joint) configurations. The maximum allowable difference is 3 mm.



11.7 Identifying overlap (any amount of overlap is unacceptable).

a gluer and for applications where the overlap of the normal glue tab is undesirable. Pressure-sensitive and heat-activated tapes have increasingly replaced gummed tapes since they are easier to apply.

Tapes can also be used in the board manufacture for reinforcing containers. Tapes can be used to provide handhold reinforcement for carrying. They can also include



11.8 Length and width of glue tabs. Minimum acceptable width is 27 mm; tabs extending more than 1.5 mm beyond horizontal male scores are unacceptable since they hinder proper step folding and cause out-of-square cases.

Table 11.5 Common case styles

0201	Regular slotted container
0203	Full-overlap slotted container
0204	All flaps meeting slotted container
0312	Half-slotted container
04 Series	Folder

easy-opening tear features and some RRP packs use the tape to turn the container into a tray to make shelf-stacking easier. Application of these tapes can only run in the machine direction of the corrugator.

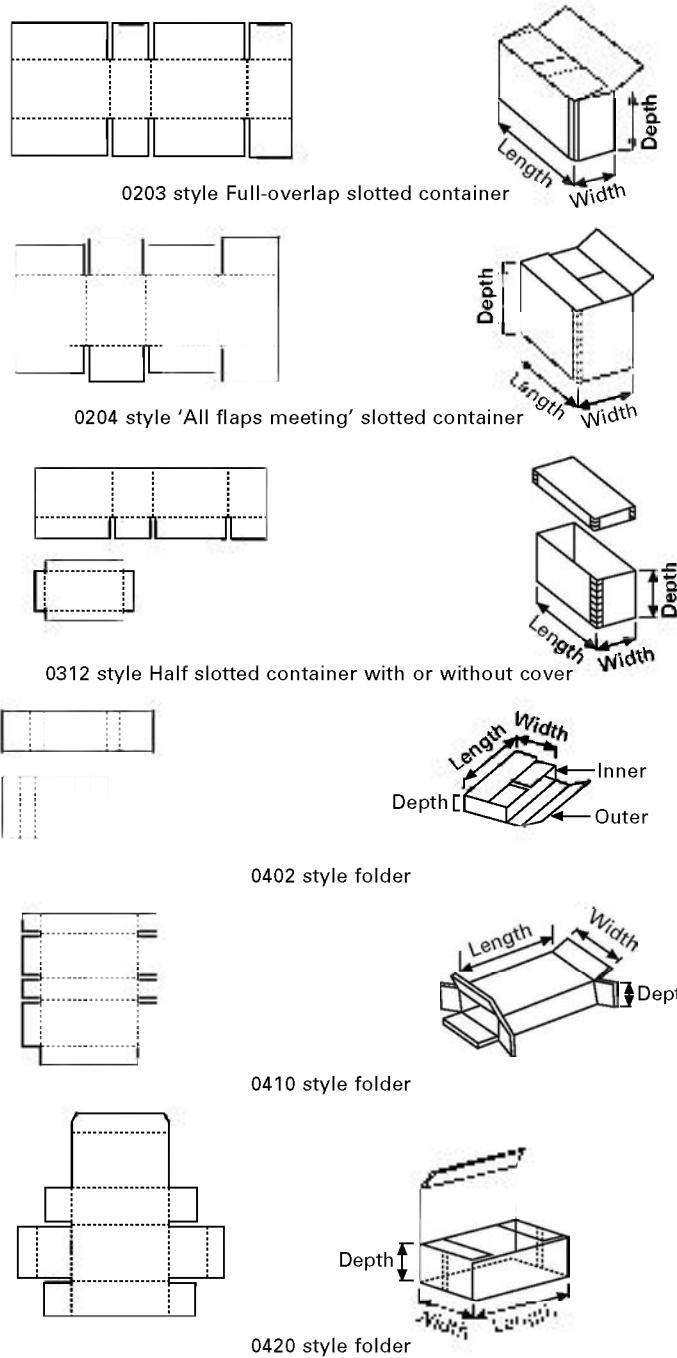
More complex designs (e.g. those needing angled or curved cuts or creases) require a die cutter which can be a flatbed press (which gives greater accuracy) or a rotary press (which is faster). The crease is pressed into the board using a scoring rule. The die can be specifically designed to incorporate special features. Die-cut designs are correspondingly more expensive than regular slotted containers. One disadvantage is that die-cutting can flatten corrugated flutes, resulting in a loss of compression strength.

#### 11.4 Different types of corrugated board container design

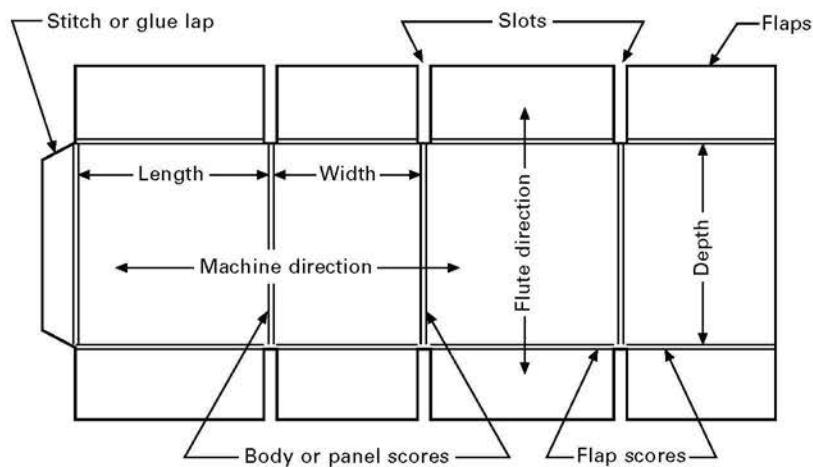
Table 11.5 lists some abbreviations commonly used to describe container types. Figure 11.9 shows examples of common case styles. There are three main basic types of container:

- regular slotted containers (RSC)
- die-cut containers
- multi-component designs.

Regular slotted containers (RSC) are containers in which all scores and cuts are in straight lines only in the machine and cross directions (see Figure 11.10). These containers are easy to manufacture on standard machinery. The manufacturer simply sets the slotters and folder-gluers to the required dimensions. Basic case designs can



11.9 Common case styles.



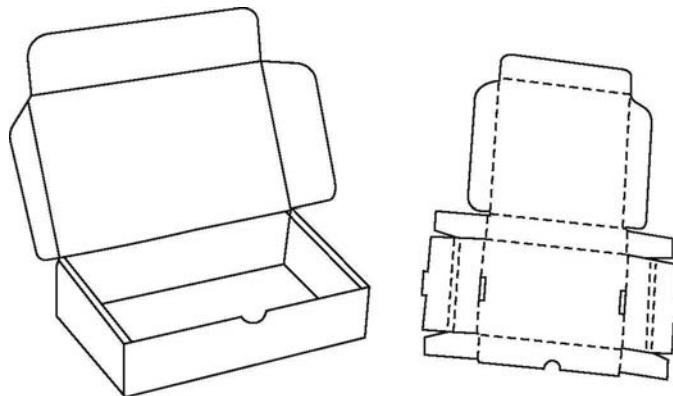
11.10 Parts of a regular slotted container (RSC) blank.

be made with or without top flaps. Variations are primarily differences in how the flaps are cut. A typical RSC has end flaps the same width as the side flaps (see Fig. 11.4). This results in an economical, rectangular master sheet and a case where the end flaps do not meet in the centre. This is known as a 0201 style.

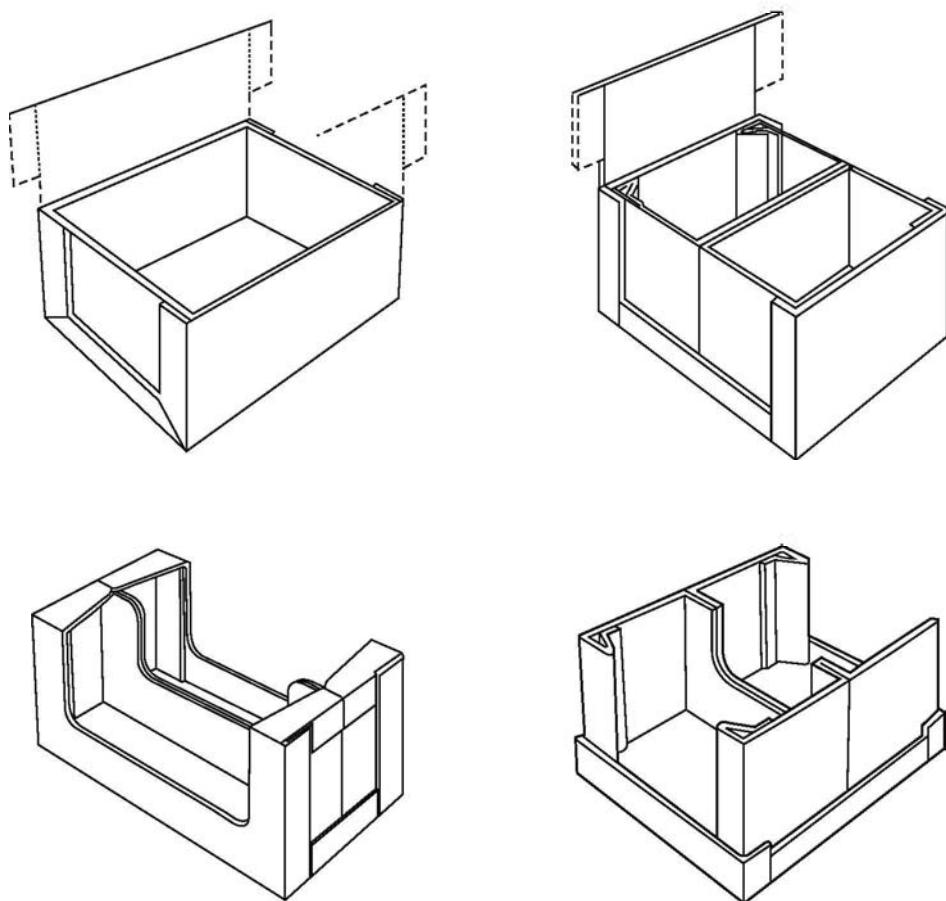
The all-flaps meeting style (0204) is used where it is important to have full, even product support across the bottom or a full, even bearing area across the top. The end flaps are cut to half the case length so that they meet exactly in the centre of the case. This style has a slightly stronger bottom than a standard RSC because of the double board layer, and is more expensive due to additional board usage. Where the container needs to hold a great deal of weight, the side flaps can be cut the full width of the container (0203 style), so that they fully overlap, rather than just meet in the centre.

Trays or open-topped cases can be made simply by eliminating the flaps at one end of an RSC (0312 style). Two trays, one slightly larger than the other, can be telescoped together to form a closed case (known as a 'box and lid'). In the produce business, a similar telescoping container is made by putting the overlapping flaps on the side and end panels, leaving the bottom as a solid sheet. This has the advantage of doubling wall thickness on the case ends, where it will contribute to top-to-bottom compression strength. The construction also uses less material unless the case is tall. Usually the body of such a case is of heavy material while the cover slide is of a much lighter stock. Folders are usually one-piece (0410 style, 0420 style) or two-piece (0402 style) constructions, often used for items such as clothing and home wares sold via mail order and for sending bottles by post.

As has been noted, die-cutting is used for more complex designs (see Fig. 11.11). As well as being more elaborate, die-cut containers are dimensionally more accurate than regular slotted containers. A third design type is shown in Fig. 11.12. These cases are assembled from a number of separate cut pieces, usually a body panel and two end panels, rather than from a single sheet. Using individual cut pieces means



11.11 Typical die-cut case design.



11.12 Multi-component case designs.

maximum utilisation of material and good compression strength. Other design variations include the incorporation of separate H partitions and triangular corner posts for greater strength. Fitments, used to separate items within a case, or to provide added strength, can be made in many styles. Some common ones are shown in Fig. 11.13.

The length of a case is always the greater of the flap opening dimensions (see Fig. 11.14). The depth is the inside dimension between the top and bottom inner flaps. The order in which dimensions are reported records where the opening will be. Top-loading cases have the largest opening for ease of loading but use the greatest board area to enclose a given volume. End-opening cases use the least board for the same volume but have the smallest opening. An end-opening case could be thought of as being the most economical, but this is usually countered by the need to die cut the blank to ensure vertical flute orientation during transit.

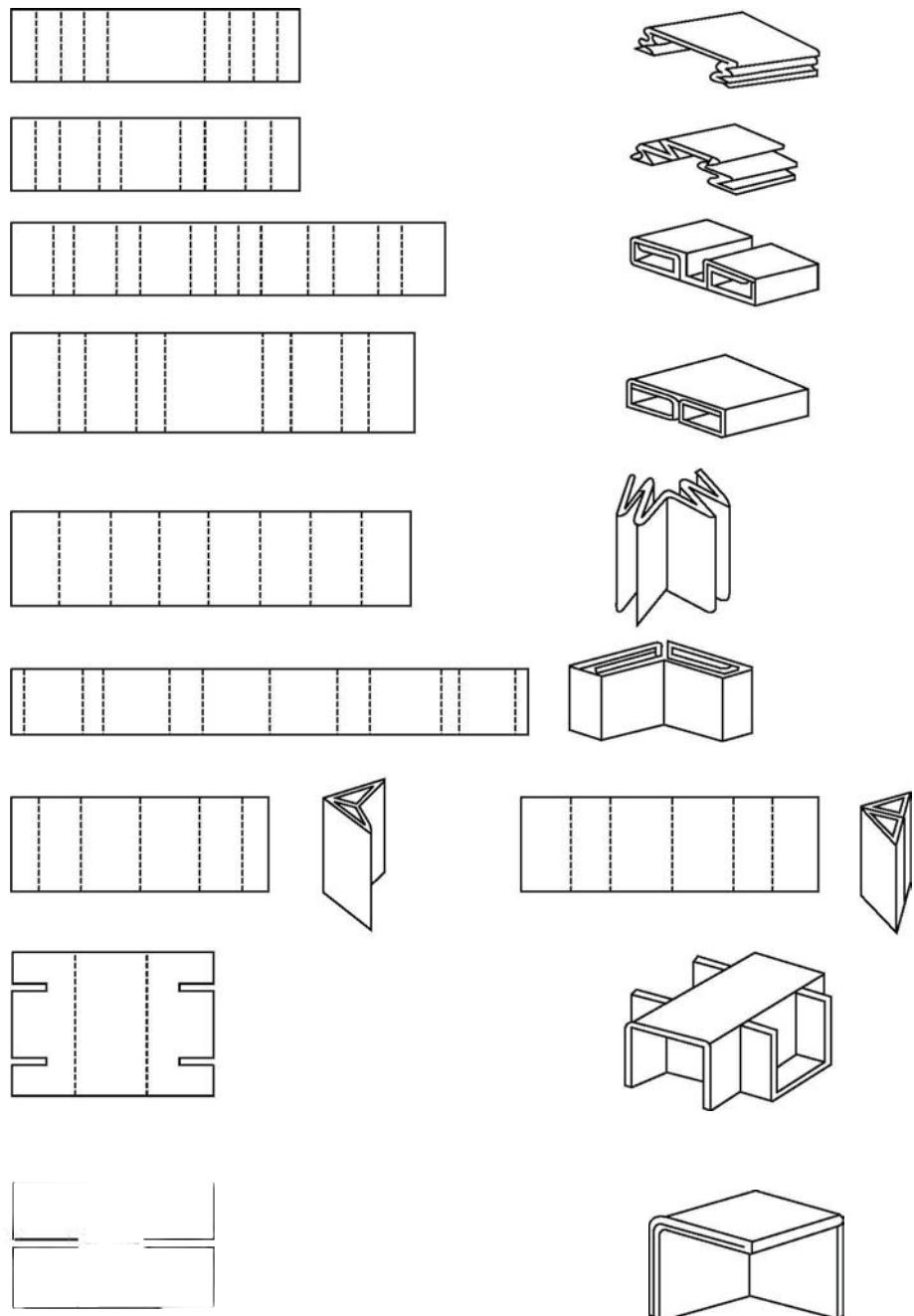
When laying out a case, allowance must be made for the material that will form the creases. Corrugated board folds by collapsing in on itself, and the lines drawn on a flat sheet will not be equal to the finished case dimensions (see Fig. 11.15). Scoring allowances are therefore added, based on the case design, flute, and material, and on the type of scoring wheels used. When discussing case sizes with a supplier, it is always best to send the product or a sample case. To size a case accurately:

1. Tear or cut the case open at the manufacturer's joint and lay it face down (see Fig. 11.16).
2. Determine case style, board, and flute.
3. Accurately mark the exact centre of the panel and end scores.
4. Accurately measure between the centre marks of the second and third panels (the W and L dimensions in Fig. 11.16). Do not measure the first or fourth panels.
5. Subtract scoring allowances as dictated by step 2 (see Table 11.6). The result is the case length and width.
6. Repeat steps 4 and 5, measuring between the end scores (the D dimension in Fig. 11.16). The result is the case depth.

## 11.5 Decoration and printing of corrugated board containers

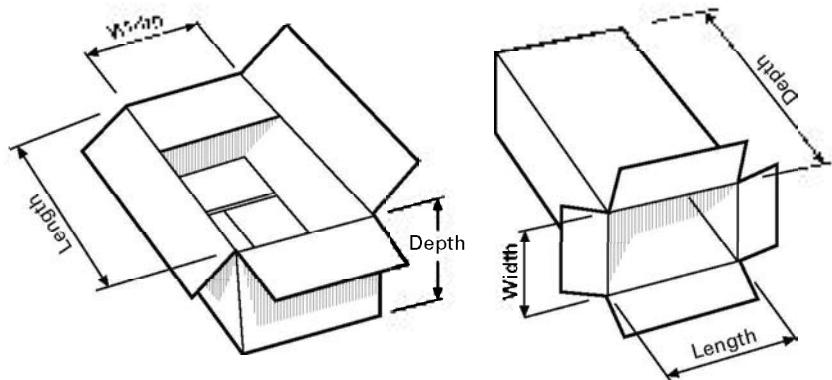
Kraft board is not an easy medium for high-quality decoration and printing. It is typically a brown colour and has a rough surface made more difficult by the fluting which also creates an uneven surface. Plain corrugated cases are typically printed using flexographic printing. Flexographic printing applies pressure to the corrugated board to effect ink transfer. Compressing the flute structure can lead to a loss in potential compression strength. If top-to-bottom compression strength needs to be maximised, heavy and multiple-colour ink coverage should be avoided. Typical allowable crush per colour is about 0.1 mm. Water-based inks are typically used.

There are various ways of improving print quality. A white Kraft liner provides a better background for printing. Oil-based inks provide a glossy finish and have good rub resistance. However, they need long drying times before further processing which

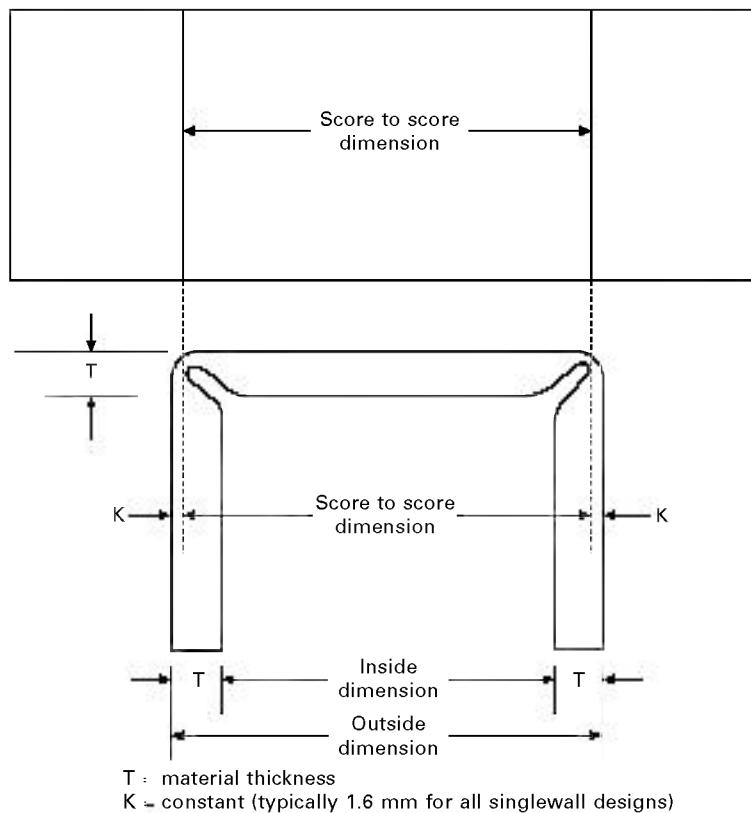


11.13 Common types of fitment.

significantly delays production. Screen printing does not need the contact pressure of flexographic printing which means it can cope better with uneven surfaces. It is also possible to laminate the entire container using lithographic printing. Alternatively,

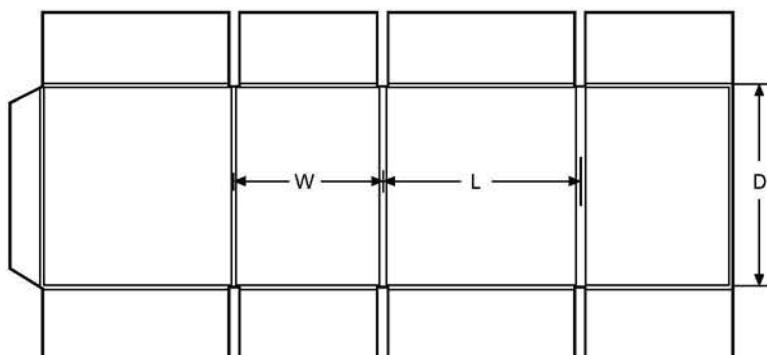


11.14 Case dimensions expressed as the inside dimensions in the following order: length, width and depth.



11.15 A flat sheet laid out with the resulting folded dimension.

labels can be used to decorate a container. White-topped Kraft liner can also be pre-printed before it is converted to corrugated board. Pre-printing eliminates the problems of trying to print an assembled corrugated board. The usual minimum



11.16 Sizing a container.

Table 11.6 Scoring allowances for board of various thicknesses

Flute	Typical score allowance
A	5 mm
C	4 mm
B	3 mm
BC	7 mm

amount for pre-printing is 2 mill rolls or several tonnes of paper. This limits the process to fairly large production runs.

There are obviously significant cost implications in the choice of print quality and the material needed to achieve it. However, this has been mitigated by the use of high-quality post-printing technology. This type of equipment is usually installed off-line, but can be linked with a die-cutting unit. As with much of this industry, the basic process has roots well back into the last century, but it is now possible to produce good quality close-registered process work due to the introduction of technical refinements. The print units use thin printing plates with flexible backing, along with vacuum transport systems to reduce undulating surface stripes, finely engraved anilox rolls to closely control ink delivery and individually driven modular print units to maintain colour registration. Such equipment can be used to print upwards of six closely registered colours with a 38 L/cm screen, resulting in good quality graphic reproduction.

## 11.6 Special board treatments

Most special treatments are concerned with maintaining container performance in humid and wet conditions, particularly tear, puncture and compression strength. Treatments can be added to the paper during milling, applied to the liner or medium as it goes into the corrugator, or added to the finished container. The latter can be advantageous if the surface treatment might make gluing less effective.

Thermoset resins (typically melamine based) can be added at the paper mill to provide greater water resistance. It is important not to exceed a content of 2% if

the paper and resulting board is not to be too brittle. Further treatment with acrylic coatings increases wet performance even further. Whilst these coatings provide good water repellency ('run-off'), they are poor in terms of moisture vapour transfer (MVT).

If the container is to be exposed to particularly wet conditions, e.g. because it has to spend some time outside such as cases and trays used at the point of harvesting fresh produce, the liner may need to contain a polymer membrane embedded between two layers of paper. This removes the likelihood of overheating the polymer layer during the corrugating process and avoids potential problems with gluing or printing.

## 11.7 Testing corrugated board materials and containers

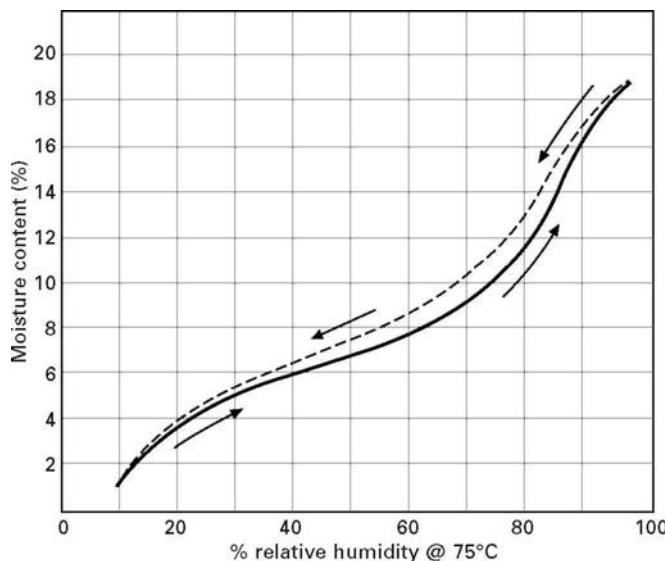
There is a range of tests for materials and containers. Only the most common are noted here. Most board tests are described in methods provided by the British Standards Institution and the Technical Association of the Pulp and Paper Industries (TAPPI). Paper mills concentrate on meeting grammage and burst value requirements. There are no specific liner caliper requirements. However, there is a move towards specifications based on other aspects of performance (e.g. edge crush test (ECT) values).

When conducting testing, it is important to be aware that the mechanical strength of paper depends on the rate at which a load is applied. The faster a load is applied, the greater the ability of paper to withstand it. Dynamic compression strength is thus higher than static compression strength. In addition, under sustained and repeated loading, paper fibres move and distort, further reducing strength. This 'creep' behaviour means that containers tested, for example, at 500 kg load compression strength in the laboratory (a fast loading rate) could be expected to fail in about a year when loaded to 250 kg in the warehouse.

### 11.7.1 Testing paper properties

One of the most important factors affecting the mechanical properties of paper is moisture content. It is therefore essential that paper testing always be undertaken at the same temperature and humidity. The internationally accepted standard is 50% RH and 23°C. The moisture content of paper depends on humidity and temperature. Paper exhibits hysteresis, i.e. the equilibrium moisture content is slightly different depending on whether the equilibrium is approached from a higher or lower initial moisture content (see Fig. 11.17).

Increasing moisture content leads to reduced compression strength. Increasing moisture content also leads to paper swelling, whilst drying makes it shrink. As an example, between 0 and 90% RH, dimensions can change by 0.8% in the MD and 1.6% in the CD. Poor humidity control can cause distortion in a blank which can compromise subsequent folding into the final container. Uneven moisture content in the outer and inner liners can cause warping as the finished board is dried. Warpage should not exceed 6 mm over a 300 mm span (as measured according to ASTM D 4727).



11.17 Equilibrium moisture content of corrugated board at various humidities.

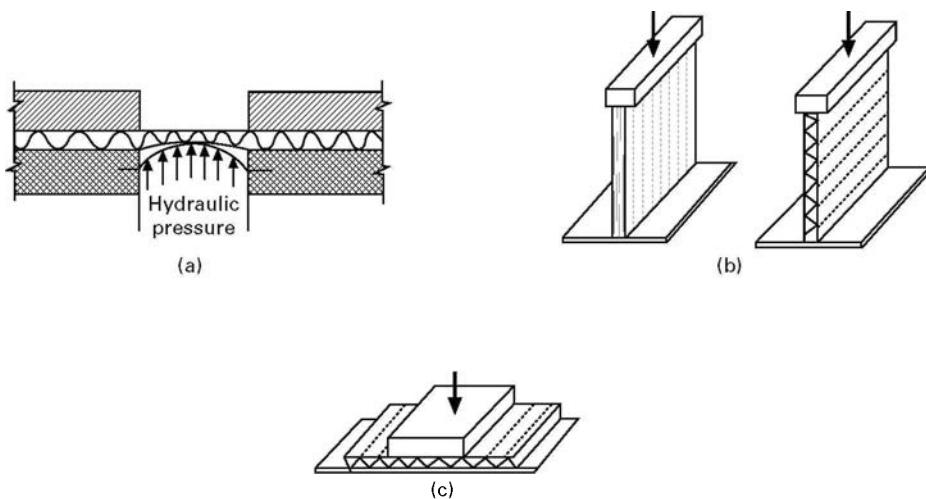
### 11.7.2 Testing mechanical strength

There is a range of tests of the strength of corrugated board materials and containers. These include:

- Mullen Burst Test (BS 3137/ISO 2759:2001)
- Edgewise Compression Test (ECT) (BS EN ISO 3037:2007)
- Box Compression Test (BCT)
- Short Span Compression (SSC) Test (TAPPI T826 & BS 7325)
- Flat Crush Test (BS EN 23035:1994/ISO 3035:1982); Concora Medium Test (BS EN ISO 7263:2008)
- Thickness of Corrugated Board Test (BS 4817: 1972 (1993)/ISO 3034:1975)
- Puncture Resistance Test (TAPPI T803; ISO 3036 & BS 4816:1972).

The Mullen Burst Test involves slowly applying hydraulic upward pressure to the fibreboard until the liner bursts and the board is ruptured (Fig. 11.18(a)). The burst strength is measured in kilopascals (kPa). If the liners are different, it is important to test both sides. A drawback is that the test is related to paper tensile strength which may not be the most important factor affecting the stiffness and compression strength of the material.

As a result, the Edgewise Compression Test (ECT) is increasingly used as an alternative. The Edgewise test involves placing a specimen of board (typically 50 × 50 mm) vertically in a compression tester and applying a load until failure occurs (see Fig. 11.18(b)). The ECT measures the stiffness of the combined facings and medium and, as a result, is a better indicator of stacking strength. Using ECT measurements, case container strength can be calculated using the simplified McKee formula:



11.18 Testing the strength of corrugated board: (a) Mullen Burst Test; (b) Edgewise Compression Test (ECT); (c) Flat Crush Test.

$$\text{Case compression strength} = 5.87 \times \text{ECT} \sqrt{\text{BP} \times \text{T}}$$

where estimated RSC top-to-bottom case compression strength is expressed in kilo-Newton (kN), ECT = edge crush (kN/m), BP = inside case perimeter (m), and T = combined board thickness (mm).

The flat crush test is similar to the edge compression test (ECT) except that the specimen is compressed in the Flat Crush Test (see Fig. 11.18(c)). The test provides a measure of flute rigidity.

The Box Compression Tester is a platen with either four columns (fixed head) or a single central column (floating head) configuration. These columns have lead screws that drive the top plate of the platen downward. An erected box is placed centrally in the tester and the platen is driven down until the point of failure is reached and measured. This test has become particularly relevant when specifying suitable material combinations for multi-piece or perforated retail ready packs (RRPs). It can be used for 'bench marking' and validation where theoretical calculations such as the modified McKee formula are unreliable due to the complexities of such packs.

As there is a strong correlation between the in-plane compression strengths of liners and fluting and ECT values, the Short Span Compression test (SCT) was developed. This allows the ECT and thence the BCT values of a given case to be extrapolated. The paper sample is clamped between the four segments of the apparatus, which has a 0.7 mm gap between the pairs of clamps. When the two pairs are driven together the length of the strip reduces and the stresses increase. As the sample is short relative to its thickness, buckling is prevented and the measured failure is due solely to compression.

Either BCT values or ECT values can be used to specify the boards used to construct a corrugated container. As a general rule, shippers interested in warehouse stacking strength find it advantageous to use BCT. Those shipping in rugged environments

or where puncture resistance from product is a concern might also use the Puncture Test (see below).

A test for evaluating laboratory-fluted samples (the Concora Medium Test) also exists. This tests the ability of the corrugated medium to keep the two liners separate. The Thickness of Corrugated Board Test is used to measure whether samples are of the required thickness (known as caliper). Reduced caliper is an excellent indicator that compression strength will be reduced. Caliper can be reduced by improper manufacture, excessive printing pressure, and improper handling and storage.

The Puncture Resistance Test tests strength by measuring the energy required to puncture a board with a triangular pyramidal point affixed to a pendulum arm. The triangular pyramidal point with 25 mm sides is forced through the board under test. The energy absorbed in forcing the tip completely through the board is reported in millijoules per metre (mJ/m).

### 11.7.3 Testing other properties

There are several other standard tests

- Water absorption: Cobb Test (DIN EN 20535:1994 ISO 535:1991)
- Porosity: Gurley Porosity Test (BS ISO 5636-5:2003); see also Bendtsen Test Method (BS 6538-2:1992)
- Water resistance: Ply Separation Test (TAPPI T812)
- Machinability: Coefficient of Friction Test.

The Cobb Test measures surface water absorption or repellency. It describes the time required to soak a specific amount of water into a corrugated sheet. The standard unit is grams per square meter ( $\text{g}/\text{m}^2$ ). The time may vary from 60 seconds to 30 minutes. The Cobb Test is used in various ways, e.g. to investigate potential gluing problems where a reasonable degree of absorption is required, or the degree of water repellency where containers may need a higher degree of water resistance.

The Gurley Porosity Test uses the time it takes for a given volume of air to pass through a paper to measure porosity. The lower the number, the more porous the paper. Porosity can vary from 2 seconds to 200 seconds but averages between 10 and 20 seconds.

The Ply Separation Test evaluates the board's resistance to ply separation when exposed to water. It is used mainly to test the effectiveness of water-resistant adhesives.

It is important to be able to measure how easily corrugated board can be formed and how well it performs in loading. If board slides too easily, it will be hard to process and use in transport and stacking. One useful measure is coefficient of friction (CoF). One method of determining CoF involves placing a weighted piece of test material onto a surface faced with the same material. The angle is gently increased until the material slips, at which point the angle is noted. The tangent of the average slide angle is reported as the static CoF. An alternative, and more accurate test is to use a stress/strain machine to measure the force required to pull a weighted specimen along a flat surface. A stress/strain machine will give both static and dynamic CoF values.

Containers with a CoF between 0.40 and 0.50 would be regarded as acceptable. A CoF below 0.40 is marginal and one below 0.30 is regarded as sub-standard. In this case some form of surface treatment may be needed to increase surface roughness to improve antiskid properties.

### **11.8 Sources of further information and advice**

- For cases (range of standard formats) and FEFCO codes, see standard formats at [http://www.fefco.org/fileadmin/fefco\\_files/fefcocodes/FEFCO\\_ESBO\\_code\\_of\\_designs.pdf](http://www.fefco.org/fileadmin/fefco_files/fefcocodes/FEFCO_ESBO_code_of_designs.pdf)
- For a detailed review of paper types used in corrugated board, see [http://www.paper.org.uk/information/technical/5\\_fibrous материалы.pdf](http://www.paper.org.uk/information/technical/5_fibrous материалы.pdf)
- Jönson, G., *Corrugated Board Packaging*, 2nd edn. Leatherhead: Pira, 1999.

# 12

## Basics of polymer chemistry for packaging materials

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**Abstract:** This chapter introduces the basics of polymer chemistry. It explains how the polymers are synthesised, including the various types of polymerisation (addition and condensation polymerisation, copolymerisation and crosslinking polymerisation). It also discusses the factors which influence the way they perform.

**Key words:** polymer, polymerisation, copolymer, plastics.

### 12.1 Introduction

'Plastic' describes the ability of a substance to be formed into an object – modelling clay, wax or dough would be good examples. The plastics which are going to be discussed in this chapter are organic and polymeric in nature. That is to say they are made from many (poly) parts (mer). Polymers do occur naturally, for example cellulose, keratin (nails and hair), shellac, rubber and DNA, but the polymers which will be discussed in this chapter are all synthesised, either from oil or other naturally occurring raw materials. All polymers used to make plastics account for less than 4% of oil used worldwide. Polymers and the plastic components made from them can meet nearly every packaging challenge. Choosing the correct polymer for a particular application is difficult without understanding their chemistry and therefore their properties. This chapter explains the essential background whilst Chapter 13 reviews the properties of polymers used for packaging applications.

A polymer is formed when a large number of units known as molecules are joined together to form a larger molecule. The units may be all the same, in which case it is known as a 'homopolymer' or two or more different units may be combined in one polymer, which then becomes a copolymer. For the packaging industry many molecules are based on a common carbon backbone, for example polyethylene (PE); others have a similar mostly carbon backbone, but with additions such as oxygen or nitrogen included in the backbone, for example polyethylene terephthalate and polyamide, respectively. The size of these molecules can be between 100 and 100,000 repeating units.

Polymers can be grouped into two basic classes:

- thermosetting
- thermoplastic, which includes thermoplastic elastomers and biodegradable polymers.

Each polymer has a unique structure and a proper chemical name (see Table 12.1).

Table 12.1 The common packaging plastics

Polymer	Abbreviation	Recycling number	Homopolymer or copolymer
Low density polyethylene	LDPE	4	Homopolymer
High density polyethylene	HDPE	2	Homopolymer
Linear low density polyethylene	LLDPE	7	Copolymer
Polypropylene	PP	5	Homopolymer
Polystyrene	PS	6	Homopolymer
Polyvinyl chloride	PVC	3	Homopolymer
Polyethylene terephthalate	PET	1	Homopolymer
Polyamide	PA	7	Homopolymer
Acrylonitrile butadiene styrene	ABS	7	Copolymer
Styrene acrylonitrile	SAN	7	Copolymer
Polyethylene Naphthalate	PEN	7	Homopolymer
Ethylene vinyl acetate	EVA	7	Copolymer
Ethylene vinyl alcohol	EVOH	7	Copolymer
Poly vinyl alcohol	PVOH	7	Homopolymer
Polycarbonate	PC	7	Homopolymer
Poly lactic acid	PLA	7	Homopolymer

As these names tend to be lengthy and in some instances difficult to pronounce, the industry has adopted acronyms for all the polymer types. This can, however, be confusing as within a polymer type there are variations which will exhibit different characteristics. Polypropylene (PP), for example, can exist in isotactic, syndiotactic, and atactic forms, determined by the chemical reaction which takes place during the polymerising process; the three forms are quite different in their properties. Copolymerisation can also change the characteristics of polymers, as can chemicals added during and after polymerisation.

The polyethylenes and polypropylene are all classed in one family, known as the polyolefins, which are all hydrocarbons, containing only hydrogen (H) and carbon (C). Substitution of hydrogen can result in a polymer with very different properties compared with the polyolefin. For example, ethylene ( $\text{CH}_2=\text{CH}_2$ ), the monomer used to make polyethylene  $-(\text{CH}_2-\text{CH}_2)_n-$  has a very poor gas barrier, but a good moisture barrier. Replacing a hydrogen atom with a chlorine (Cl) atom results in a polymer with a greatly improved gas barrier but reduced moisture barrier. This resultant polymer is PVC, or polyvinyl chloride.

Traditionally polymers for the production of plastics (the name given to the macromolecule produced by polymerisation) were sourced from oil or coal, although it has always been possible to obtain the basic units to make many of the common plastics from other sources such as plants and trees. Recent developments have resulted in the production of biodegradable plastics such as PLA (polylactic acid) from renewable cereal and vegetable raw materials. This has added to the challenges of recycling as these new polymers are meant to go into special industrial composting and regeneration facilities and must not be mixed with conventional polymers for recycling.

## 12.2 The basic principles of polymerisation

Packaging polymers are based on the carbon atom. Carbon has the ability to:

- Form four bonds with other atoms. Carbon (C) is an atom; methane  $\text{CH}_4$  is formed when carbon bonds with four hydrogen (H) atoms and is called a molecule.
- Join to itself to form long chains, either in a line (-C-C-C-C-C-) or as a branched structure (-C-C-C-C-C-C-):



The structure of the polymer, as will be discussed later, is very dependent on the polymerisation methods and initiators used. In this chapter the chemistry is going to be kept to a minimum. The emphasis will be on the key aspects of the structure and manufacture of polymers and how these affect properties and performance in use.

Monomers are, in the main, obtained from the fractional distillation of crude oil followed by catalytic cracking of the resultant fractions. Fractional distillation involves heating the crude oil in a large fractionating column, where different fractions are separated by virtue of their different boiling points, determined by the number of carbon atoms in the hydrocarbon chain. The higher the number of carbon atoms, the higher the boiling point. The ratio of the different fractions is fixed according to the source of the crude oil, and to obtain more supplies of the most needed fractions, e.g. gasoline, some of the less useful, longer chain structures are 'cracked' or broken down into smaller fractions. Molecules with two or three carbon atoms such as ethene ( $\text{CH}_2=\text{CH}_2$ ) and propene ( $\text{CH}_2=\text{CH}_2-\text{CH}_3$ ) are the by-products of this cracking process and are, in turn, polymerised to make polyethylene and polypropylene using the addition polymerisation method.

Carbon atoms can easily attach to each other and this can be either via a single bond ( $\text{CH}_3-\text{CH}_3$ ), known as ethane which is a very stable structure, or a double bond, forming a less stable structure such as ethene or ethylene ( $\text{CH}_2=\text{CH}_2$ ). Ethane is stable because it is *saturated*, which means that each carbon atom is attached to the maximum possible number of hydrogen atoms. Ethene, on the other hand, is an example of an *unsaturated* molecule, as it does not contain the maximum number of hydrogen atoms, resulting in the two carbon atoms being joined by a double bond. This double bond can be easily broken down and this is the basis of the polymerisation process to be discussed below.

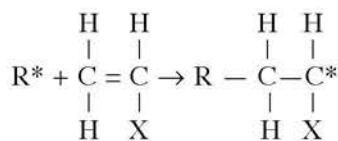
As stated, monomers can also be obtained from renewable resources such as trees and plants. This includes monomers which can be synthesised to produce common polymers (e.g., polyethylene) as well as the monomers which can be extracted to produce bio-compostable polymers such as polylactic acid.

### 12.3 Addition (chain growth or coordination) polymerisation of polymers

Many polymers with starting monomers that are similar in structure, such as polyethylene, polypropylene, polystyrene and polyvinyl chloride, are produced by addition polymerisation. There are two different methods described below, that are illustrated by comparing the polymerisation of LDPE with the polymerisation of HDPE.

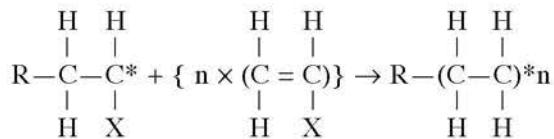
#### 12.3.1 Polymerisation of low density polyethylene (LDPE)

Low density polyethylene is produced by *free radical polymerisation*. A free radical is a molecular fragment that contains an unpaired electron, often as a result of molecular decomposition or reaction of a molecule with another free radical. Free radicals are obtained from organic peroxides ( $R-O-O-R'$ ), hydroperoxides ( $R-O-O-H$ ) or azo compounds ( $R-N=N-R'$ ). Ultraviolet light and high temperatures are sometimes used to generate the free radicals. Free radicals are unstable in themselves as they need a partner, and they look for stability by attacking an unsaturated monomer, i.e. one with a double bond ( $C=C$ ). The weak double bond breaks and the free radical attaches itself to the monomer, creating a larger free radical as shown below:



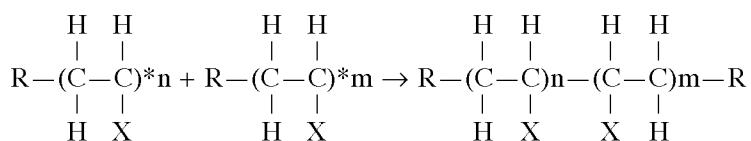
where  $C$  = carbon,  $H$  = hydrogen,  $X$  = another atom or molecule, for example hydrogen (ethylene), chlorine (vinyl chloride) or a methyl group ( $CH_3$ ), producing propylene. This is the initiation step.

The reaction continues and, each time, a monomer is added to the growing chain, resulting in added repeat units, increasing the size and molecular weight of the polymer to the pre-determined level ( $n$  = number of repeat units;  $*$  is the free radical):

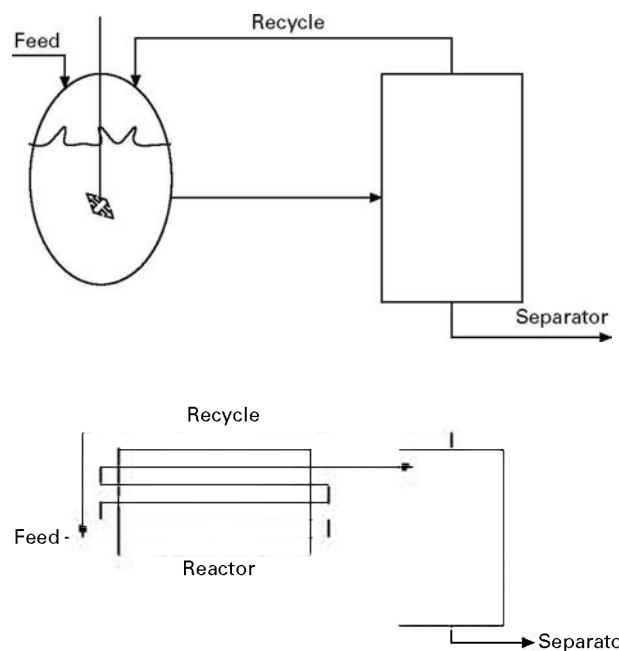


This is the propagation stage which continues until the polymer is the size and average molecular weight required.

Next comes the termination stage at the required point. There are many ways of terminating polymerisation. The one illustrated below shows how two free radical polymers are combined. The two free radicals cancel themselves out by reacting with each other, resulting in a stable molecule. There is no longer any propagation and the reaction is stabilised. (NB:  $m$  and  $n$  are number of repeat units,  $m$  is a different number to  $n$ ):



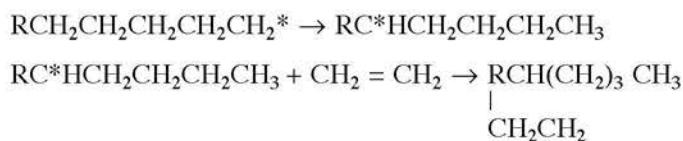
Polyethylene can be produced using either an autoclave or a tubular reactor (Fig. 12.1). Autoclaves are large vessels in which a product is agitated (stirred). These are used in the high pressure (103,000–344,000 kPa) process required for the production of low density polyethylene. Ethylene at this pressure and temperature (125–250°C) acts as both a gas and a liquid and therefore is its own solvent (other monomers use a separate solvent).



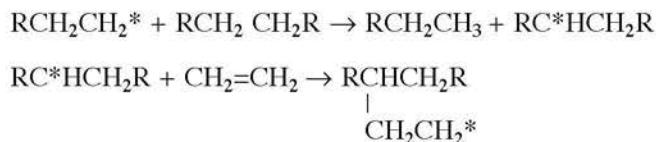
12.1 Autoclave and tubular reactors for processing polyethylene.

The autoclave process produces highly branched random polymers due to the fact that the free radical initiator and the monomer are randomly mixed as the polymer chain is growing. In these circumstances a free radical can react with a monomer as already discussed, or it can extract a proton thus destabilising the atom within the molecular chain. This creates a reaction site within the chain, resulting in a branch being formed.

Depending on where this happens along the polymer chain, short or long chain branching can occur. If the attack occurs near the free radical, as usually happens, a short branch is formed. If the site of attack is a long way from the end of the polymer chain, a long branch is formed. An example of short chain branching is:



An example of long chain branching is:



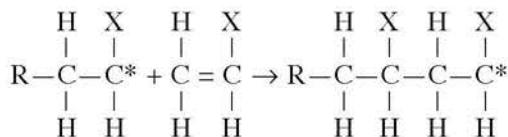
The tubular reactor results in a lesser branched LDPE than the autoclave method, due to the controlled way in which the initiators are added. Tubular reactors are commonly used to make LDPE for film manufacture.

### 12.3.2 Polymerisation stereochemistry of high density polyethylene (HDPE)

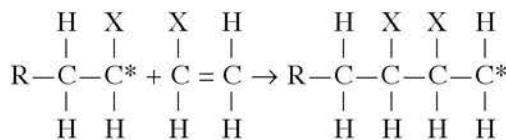
HDPE is produced by *coordination polymerisation* using a catalyst, usually Ziegler-Natta (ZN). This controls the combining of the monomer, polymerisation taking place on the catalyst's surface. Pressure is much lower than in the free radical process, commonly around 2,000 kPa. Polymerisation takes place in the presence of a small quantity of hexene ( $C_6H_{12}$ , containing one double bond), which is added to reduce the branching and control the crystallinity to the requirements of its end use. Film grades normally have a density of 0.956 g/cm<sup>3</sup> having less than 10 branches per 1,000 carbon atoms). Polymerisation takes place in a solution, slurry or gas phase:

- Solution phase is where the monomer acts as a solvent for the polymer being produced (it is dissolved in its monomer).
  - The slurry phase utilises a solvent to dissolve the monomer and suspend the catalyst. As the polymer reaches high molecular mass, it is no longer soluble and therefore drops out of solution, creating a slurry.
  - Gas phase polymerisation is carried out in a fluidised bed of the catalyst in a vertical tower. The ethylene percolates through the catalyst, polymerises and precipitates out as a powder. Molecular weight distribution (discussed later) is controlled by the type of catalyst used and the reactor conditions employed.

Tacticity relates to the way non-uniform three-dimensional polymer molecules such as polypropylene are formatted within a polymer chain. In the case of addition polymerisation of polymers other than polyethylene such as PP homopolymer, PVC, PS and PVOH, other interactions can come into effect. One of these is 'head to head' versus 'head to tail' configurations as shown below:

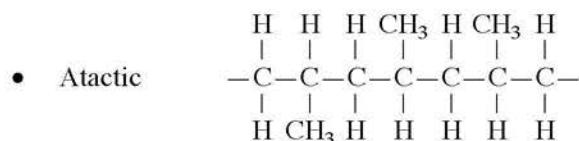


A head to head configuration is:

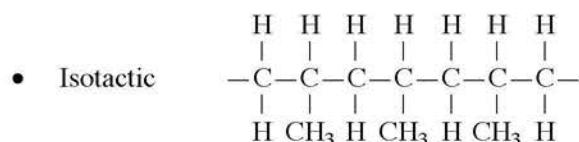


The position of the X (e.g. OH in PVOH) when it reacts with the free radical affects its position in the chain. In general, free radical polymerisation produces head to tail, rather than head to head configurations. The CHX group is considered as the head and the CH<sub>2</sub> group the tail. The major reason for this phenomenon is stability of the free radical in the head to tail configuration.

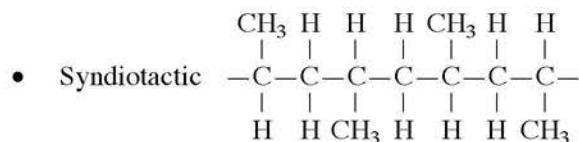
The configuration of a polymer molecule is not just dependent on which atom is attached to which but also tacticity. Polypropylene, for example, can exist in three tactic forms:



All the methyl (CH<sub>3</sub>) groups are randomly spread either side of the carbon chain.

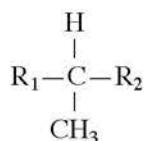


The methyl groups are all on one side of the carbon chain.



The methyl groups alternate around the carbon chain.

For this tacticity to occur, the polymer chain must contain a 'chiral' carbon, which is one with four different constituents attached to it. For example, in the case of polypropylene:

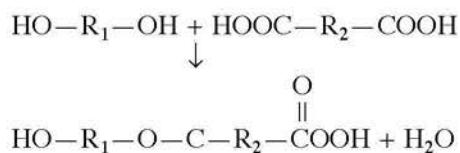


R<sub>1</sub> is a polymer chain of length X and R<sub>2</sub> a polymer chain of length Y and therefore there are four separate constituents attached to the carbon. Different catalyst systems

can produce different tacticity, resulting in different properties (discussed later and in Chapter 13).

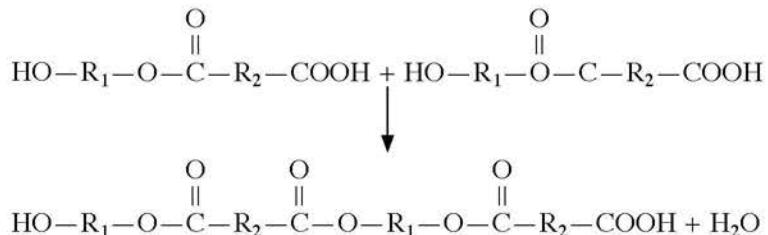
## 12.4 Condensation (step) polymerisation

Condensation polymerisation results from the reaction between molecules of different functional groups, for example COH (alcohol), CNH<sub>2</sub> (amine) or COOH (acid). The first step is to react, for example, a dialcohol with a diacid to form:



The alcohol and acid groups react together forming a molecule having two different functional (reactive) groups at opposite ends. (Note that if more complicated monomers were reacted together, having three functional groups, a crosslinked polymer would result.) During the reaction there is the loss of a small molecule, n, in this case water as condensate.

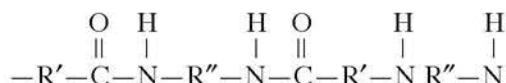
In the second step, the intermediate monomer, having dual functionality, can react with a similar monomer:



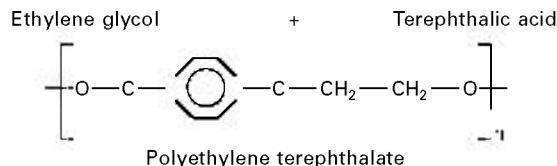
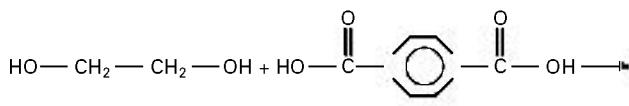
This reaction will continue until the condensation polymer of predetermined molecular weight is achieved.

In the above reaction, if n molecules of terephthalic acid are reacted with n molecules of ethylene glycol, polyethylene terephthalate (PET) is the result (Fig. 12.2). PET can also be synthesised from dimethyl terephthalate. Other condensation polymers can be synthesised. These include polyamides (PA), polyethylene naphthalate (PN) and polycarbonate (PC) as well as polylactic acid.

### Polyamide

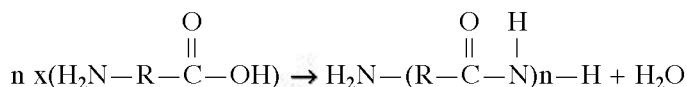


Polyamides can be formed by reacting a diamine with a diacid. The choice of monomers to form the intermediate monomer in the first step of polymerisation

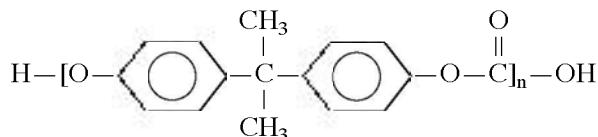


12.2 PET polymerisation.

determines the end molecular structure and therefore the final functional properties. Polyamides can also be produced using amino acids as the starting monomer. In this instance an intermediate is not necessary:



#### Polycarbonate



Polycarbonate is produced from phosgene ( $\text{O}=\text{C—Cl}_2$ ), a poisonous gas which is a derivative of carbonic acid ( $\text{HO—C}(=\text{O})\text{—OH}$ ) and bisphenol A to produce poly(bisphenol A carbonate), known as polycarbonate.

#### Polylactic acid

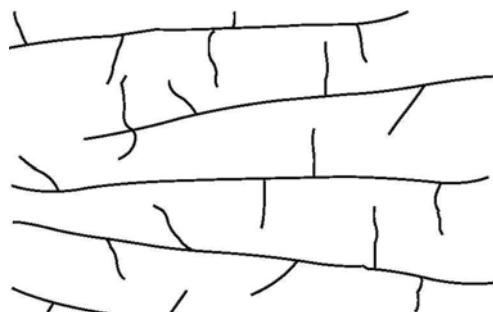
Polylactide or polylactic acid (PLA) is a synthetic, aliphatic (containing no benzene ring) polyester produced from the monomer lactic acid. Lactic acid is found in plants as a by-product or intermediate product of their metabolism. Lactic acid can be industrially produced from a number of starch or sugar-containing agricultural products, such as cereals. There are three mechanisms by which lactic acid can be produced. These are:

- ring opening polymerisation (ROP),
- direct polycondensation in high boiling solvents (DP, S), and
- direct polymerisation in bulk followed by chain extension with reactive additives.

ROP is the favoured production route for the majority of polylactic acid produced.

## 12.5 Copolymerisation and crosslinking polymerisation

A copolymer is a polymer made from more than one monomer type. If the copolymer is made up of say, x units of propylene and z units of ethylene, polymerised together under the same conditions, it will contain the number of units of each in the proportions used. Therefore a large range of ethylene/propylene copolymers is possible depending on the ratio of each monomer used in the reaction. In this way the manufacturer of such a polymer can control some of the properties of the resultant resin. This can be carried out for any monomer suitable for addition polymerisation. For example, if hexene, heptene or octene are copolymerised with ethylene, the result is LLDPE (linear low density polyethylene) (see Fig. 12.3). This copolymer has much more elasticity than LDPE; the larger the carbon chain in the comonomer, the greater the elasticity. The hexene version might be used for carrier bags whilst the octene version, due to its greater elasticity, might be used for stretch wrap.



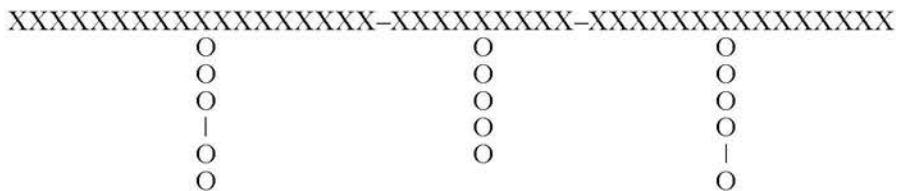
12.3 Linear low density polyethylene.

The molecules of each copolymer can be arranged, with respect to the other, in a random, alternating, block or graft format. This also allows the polymer manufacturer to design the polymer to meet the needs of the customer throughout the supply chain. The main types of copolymers are listed below.

- Random copolymers, as the name suggests, involve an uncontrolled distribution of the two polymers, resulting in a totally disordered polymer chain –OOXOOOXXOOXOOXXXXOOXOOOOXXOOOX–OXOXOXOXOXOXOXOX, where X and O are the two monomers. Random copolymers can be formed by adding the second polymer to the first, during random polymerisation of the first, e.g., the addition of ethylene during the random polymerisation of polypropylene.
- Alternating copolymers have a backbone where X and O share equal proportions –OXOXOXOXOXOX–OXOXOXOXOXOXOX. The polymerisation of an alternating copolymer is more complicated. They can only be produced if the reaction rate of one growing polymer chain (X) is faster than the other (O). If this is achieved, then the majority of the polymer chain is of an alternating structure.
- Block copolymers can vary in the proportion of each monomer used to make the copolymer. Each monomer type forms in a block of its own such as

—XXXXXOOOOOOXXXXXOOOOOOOO—XXXXXOOOOOO. One way that a block copolymer can be produced is to polymerise each monomer separately to a low degree of polymerisation and then combine these small polymer molecules with one another. Alternatively, if molecules are introduced into the reactor in an alternating sequence, a block copolymer will also result.

- Graft copolymers have a backbone of one type of polymer and branches of another, e.g. high impact polystyrene (HIPS). It has a polystyrene backbone with grafted polybutadiene branches:

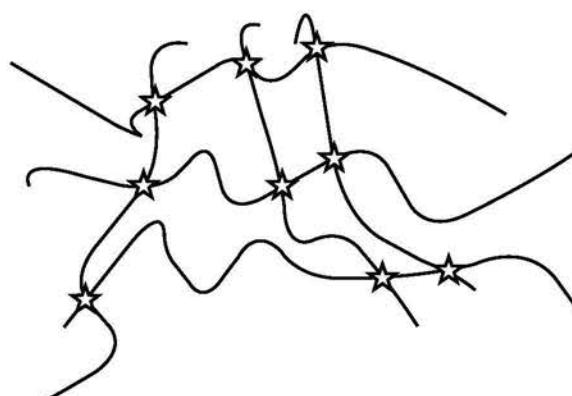


Graft copolymers are often formed by building reactive sites into the linear backbone; the subsequent branching occurs at these sites.

Combination can occur of copolymer types. For example, acrylonitrile butadiene styrene (ABS) occurs in two stages, combining a random copolymer of styrene acrylonitrile (SAN) with a branch of butadiene grafted onto the random copolymer backbone.

### 12.5.1 Crosslinking polymerisation

Multifunctional monomers have three or more reactive sites which can bond to one another forming a crosslink, instead of merely forming branches. The polymer chains link together to form a network due to very strong interactive forces to form a two- or three-dimensional structure. Crosslinked polymers are not commonly used in packaging but have important applications, especially where chemical and temperature resistance is required, for example as coatings to protect metal cans from attack during processing and in storage (see Fig. 12.4 and Chapter 8).



12.4 Crosslinked polymer (star indicates crosslink).

## 12.6 Factors affecting the characteristics of polymers

There are many factors which influence how a particular polymer will perform and the following will now be discussed:

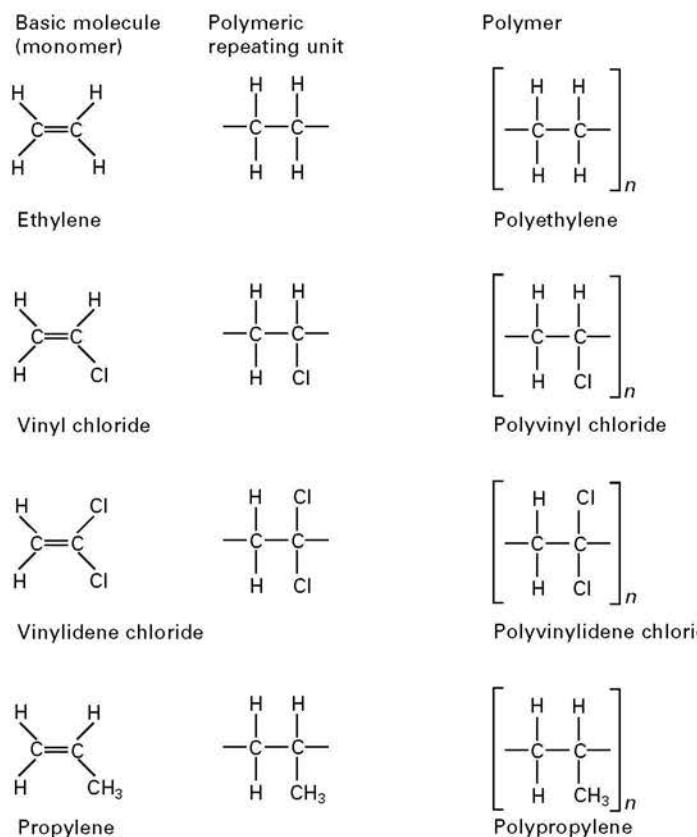
- the monomer from which the polymer is formed
- tacticity
- the way in which the monomer is polymerised
- the degree of crystallinity of a polymer
- the molecular weight and molecular weight distribution within the polymer
- how many monomers have been used to make the polymer
- the orientation of each monomer in a copolymer
- the type of inter-and intra-molecular forces within the polymer structure
- the additives within a polymer mix, ready for processing into packaging
- the use of special treatments
- mixing polymers in an orderly manner
- the physical orientation of a polymeric packaging plastic.

### 12.6.1 The monomer from which the polymer is formed

The monomer has a profound effect on the properties of the polymer formed from it. It can be seen from Fig. 12.5 that the four monomers shown are very similar with a hydrogen atom in ethylene being substituted with another atom or functional group. The change may appear to be small but the effect on the properties of the resulting polymer is considerable. For example, polypropylene has the best barrier to moisture, followed by polyethylene, polyvinyl chloride and lastly polyvinylidene chloride.

The size of the replacing atom in comparison to hydrogen is also important. The larger the atom or functional group, the more difficult it is for it to rotate about the central carbon backbone. This is known as steric hindrance. The hydrogen atoms in polyethylene are small and therefore present very little hindrance to rotation. As a result its  $T_g$  (glass transition temperature – the temperature at which a plastic changes from a ‘glassy’ to a ‘rubbery’ state) is very low at  $-60^\circ\text{C}$ . Polystyrene has a large benzene ring substituting the hydrogen atom, thus greatly impairing rotation about the carbon backbone, and it has a  $T_g$  of  $+100^\circ\text{C}$ . Polypropylene has a methyl ( $\text{CH}_3$ ) group which hinders rotation less than polystyrene but more than polyethylene and it has a  $T_g$  of  $-15^\circ\text{C}$ . As the steric hindrance increases, stiffness increases. Therefore you can predict that packaging made from polypropylene homopolymer is stiffer than polyethylene but not as stiff as polystyrene homopolymer.

The polarity of monomers and therefore the polymers synthesised from them varies. Non-polar polymers such as polypropylene and polyethylene have very low surface energy; as a result they are difficult to bond and therefore difficult to print. Special treatments have to be applied to the surface of such polymers to enable printing inks to bond to the surface. Such treatments include corona discharge (high voltage, low amperage electric current) and flame treatment of the surface. These treatments oxidise the surface of the polymer, increasing the surface energy to above 40 dyne/cm, which means that there is sufficient energy to accept adhesives and printing



12.5 Four very similar monomers with a hydrogen atom in ethylene being substituted with another atom or functional group. The change may appear to be small but the effect on the properties of the resulting polymer is considerable.

inks. If the surface energy is too low, the adhesive or printing ink will not wet out the surface of the substrate; it will reticulate, forming globules on the surface and hindering bonding.

Another factor affected by the non-polar nature of a polymer is barrier. Polyethylene and polypropylene repel polar water but not non-polar gasses, such as oxygen. Therefore they have good moisture and water barrier but very poor gas barrier. Polyvinyl chloride is much more polar than polyethylene and therefore does not require its surface to be re-energised to accept adhesive or print. It also has a better gas barrier than polyethylene but only a fair moisture barrier. Often polar polymers are mixed with non-polar polymers to enhance their performance. For example, ethylene vinyl acetate (EVA) is often added to polyethylene to give it a cling property, which is useful in stretch wrap film.

The chemical make-up of the polymer influences such properties as density, thermal properties, melting and softening point, solubility, and permeability to gases and

moisture vapour. Density is directly related to how many square metres one tonne of polymer will produce. The mass per given volume is dependent on the mass of the atoms in the polymer's make-up. For example, PVC has a higher molecular mass than LDPE due to the higher mass of the chlorine atom. The amount of branching and the strength of the intermolecular forces, which draw the polymer molecules together, also affects density. The closer the molecules are to each other, the less the space between them and therefore the higher the density, for example HDPE compared to LDPE. The atoms contained within a molecule, the forces bonding them to other atoms (intra-molecular), the forces between molecules (inter-molecular) and the randomness of the polymer chains in relation to one another all affect the melting temperature ( $T_m$ ), the glass transition temperature ( $T_g$ ) and the decomposition temperature.

Polymers that have no hydroxyl groups, such as the polyolefins (PE, PP, etc.), are hydrophobic (water hating), while others with hydroxyl groups, such as polyvinyl alcohol (PVOH), are hydrophilic (water loving); therefore PVOH will dissolve in water. The polyolefins have a high resistance to water. Polymers which have a percentage of hydroxyl groups such as polyethylene vinyl alcohol (EVOH) and polyethylene terephthalate (PET) will not dissolve in, but will absorb, water.

Polarity of the monomer or monomers which make up the polymer has an effect on whether the polymer will provide a good barrier to gas or moisture: for example, a polar polymer such as PVC has a much better barrier to gases such as oxygen than do the polyolefins which have no polarity. The polyolefins, however, have a much better barrier to moisture than their polar alternatives. The more linear a polymer chain is, the better the barrier properties due to the fact the chains are closer together and therefore there are fewer gaps for the gas and moisture particles to pass through.

Polymer chain length also affects the properties of the polymer. Mechanical strength, melt viscosity and melting temperature ( $T_m$ ) are just some of the properties which are affected by the molecular weight (MW) of the polymer. The longer the chain length, the greater the number of repeat units, the higher the molecular weight (molecular mass) of the polymer.

As molecular weight increases, the mechanical strength, such as tensile properties and stiffness of a polymer chain increases, due to the greater inter-molecular forces exerted within the polymer. These forces also play their part when a polymer melts and this, combined with the greater entanglement of the polymer molecules with each other, restricts their flow and therefore the resultant melt has a higher melt viscosity. The greater the intra- and intermolecular forces contained within a polymer, the greater the energy required to break down the forces to allow the molecular chains to move freely (melt). The higher the molecular weight, the higher the forces and the higher the temperature required to melt the polymer.

### 12.6.2 Tacticity

Tacticity of a non-uniform monomer such as propylene in a polymer chain affects the  $T_g$  of the polymer. In the last section it was said that polypropylene had a  $T_g$  of  $-15^\circ\text{C}$ , but this depends on the tacticity. For example, atactic polypropylene has

a  $T_g$  of  $-19^\circ\text{C}$ , whereas isotactic polypropylene has a  $T_g$  of  $-8^\circ\text{C}$  and therefore is much more likely to embrittle at temperatures used in the storage of frozen food ( $-18$  to  $-40^\circ\text{C}$ ). Tacticity can also affect other properties: isotactic polypropylene has higher strength and a higher  $T_g$  and  $T_m$  than all other common polyolefins, and syndiotactic polypropylene in film form has higher elasticity than other homopolymer polyolefins.

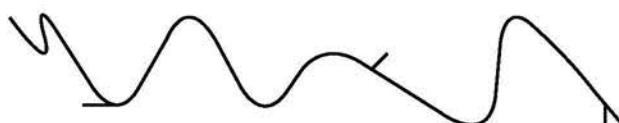
### 12.6.3 Polymerisation methods, initiators and catalysts

Low density polyethylene is produced by using high temperature and pressure with an organic peroxide providing the free radical initiator. This produces a branched polymer, as shown in Fig. 12.6, with low crystallinity. High density polyethylene is produced at low temperature and pressure and uses an organometallic catalyst. This produces a linear polymer of higher crystallinity with few branches along the polymer chain (Fig. 12.7).

Changing the catalyst (e.g., from a Ziegler-Natta to a metallocene) can change the properties of the polymer, due predominantly to the much narrower molecular weight distribution produced. ZN catalysts have three different sites on the catalytic particles; one site producing high molecular weight (MW), another medium MW and the third lower MW. Therefore the molecular weight distribution (MWD) is wide. Metallocene catalysts have only one site and therefore the MWD is narrower, resulting in lower density polymers with improved physical properties such as clarity in the resultant plastic film or moulding. Effects of molecular weight and molecular weight distribution on the flow properties of a polymer can be determined by measuring the melt flow



12.6 Branched polymer showing short and long chain branching (e.g. LDPE).



12.7 Linear polymer (linear polymers can have very minor amounts of branching. Examples are HDPE, LLDPE, PET, PA, PVC and PS).

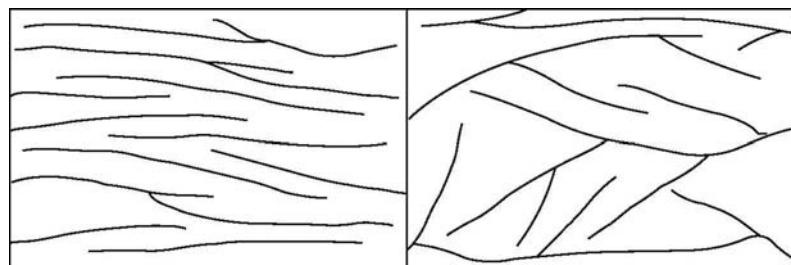
index (MFI) of the particular polymer. The wider the molecular weight distribution for a given average molecular weight of a polymer, the less is the resistance to flow (viscosity) and the higher the MFI.

#### 12.6.4 Crystallinity

Crystallinity, as applied to polymers, can be defined as the fraction of a polymer that consists of regions showing three-dimensional order. All polymers have some degree of crystallinity. Those with little crystallinity are known as amorphous polymers, for example low density polyethylene or amorphous polyethylene terephthalate (APET), and those with a high degree of crystallinity are known as crystalline polymers, for example high density polyethylene or crystalline polyethylene terephthalate (CPET).

Figure 12.8 shows polyethylene homopolymer in its two main forms, high density polyethylene (HDPE) on the left, and low density polyethylene (LDPE) on the right. The branching seen in LDPE prevents the molecular chains from packing close together, reducing density and subduing crystallinity. HDPE, on the other hand, has few or no side chains and therefore the molecular chains can pack closely together, resulting in HDPE having a higher density, and because the chains can align themselves to one another, a greater degree of crystallinity.

Table 12.2 shows the progression from LDPE to HDPE and beyond. The conclusions drawn from this are that as density increases so does crystallinity, resulting in increases



12.8 Polyethylene homopolymer in its two main forms: high density polyethylene (HDPE) on the left, and low density polyethylene (LDPE) on the right.

Table 12.2 Progression from LDPE to HDPE and beyond

0.91 LDPE	0.92 MDPE	0.93 MDPE	0.94 HDPE	0.95 HDPE	0.96 UHDPE	0.97 UHDPE
65%			Crystallinity			95%
Lower			Stiffness			Higher
105°C			Softening point			126°C
13.5 mPa			Tensile strength			30 mPa
500%			Elongation			20%
Lower			Barrier			Higher
Lower			Grease resistance			Higher

in stiffness, softening and melting points, tensile strength, barrier to moisture and gases and resistance to oil and grease. At the same time the amount the polymer will stretch and its transparency will decrease. There is, however, an exception to the transparency rule. Crystals are present in all polymers. If the crystals are large enough and of differing sizes, they will reflect and refract (alter the linear path of light by changing the angle of the path it is travelling in) light in all directions, causing the plastic to lose transparency. If the crystal formation sites are kept small by preventing the site from growing and their size is less than the wavelength of visible light, refraction is prevented. Special nucleating agents can be added, providing a wide range of benefits including the deliberate inducement of the formation of small crystals, for example where clarity of polypropylene copolymer is required for bottle manufacture.

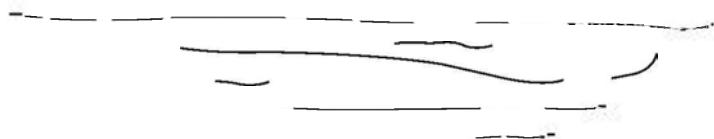
#### 12.6.5 Molecular weight and molecular weight distribution

The longer the polymer chain, the higher the molecular weight for any given polymer type. The type of polymerisation and the initiator or catalyst used will affect the molecular weight distribution. As the number of units increases, we move from simple monomers, which are normally gaseous, through to liquids and then waxy materials (oligomers), finally reaching the solid polymeric material we know as plastic. The size of the polymer is normally expressed as molecular weight (MW) or molecular mass.

As the molecular weight (measured as an average molecular weight of a polymer) increases, the melting temperature increases as does the viscosity of the melt, making it more difficult to process, but mechanical properties such as tensile strength and stiffness improve, which is a benefit. Processors therefore have to compromise between ease of manufacture and improvement in mechanical properties, based on the needs of their customers.

However, polymerisation is not that uniform. In every polymer of a particular molecular weight there will be a variation of chain length within the polymer, referred to as the molecular weight distribution. Figure 12.9 is a pictorial representation of the variation in molecular chain length (molecular weight) of an addition polymer such as polypropylene. Chain length can vary from 100 to over 100,000 repeat units.

This variation affects the properties of the polymer. If we can predetermine the molecular weight distribution, for example by using a metallocene catalyst, we can have better control over the final properties of the polymer. The molecular weight



12.9 Pictorial representation of the variation in molecular chain length (molecular weight) of an addition polymer such as polypropylene.

can be the same but if the molecular weight distribution is less, then the mechanical properties such as tensile strength are greater. However, the melting temperature range is shortened as is the heat sealing temperature range and the melt flows less readily; all of which could be detrimental if using a film to heat seal to a rigid container. Polymers with a wide molecular weight distribution will melt over a greater temperature range than polymers with a narrow molecular weight distribution and, if both polymers have the same average molecular weight, the one with the narrower range will have a higher melting point.

#### 12.6.6 Number of different monomers in a polymer

A homopolymer will have the characteristics of its monomer type – ethylene to polyethylene, propylene to polypropylene, for example. However, if we combine the two monomers to form a copolymer we can use one monomer to improve the properties of the other. Polypropylene homopolymer (depending on tacticity) has poor low temperature properties, is difficult, if not impossible, to extrusion blow mould due to its low melt strength and it can be used for blown film only if a special process is used (see Chapter 14). It also has poor clarity. By copolymerising with ethylene, it is possible to overcome most of these difficulties (with the exception of blown film).

Another good example of improving performance by moving from a homopolymer to a copolymer is the copolymerisation of ethylene with one of the higher olefins such as hexene ( $C_6H_{12}$ ), heptene ( $C_7H_{14}$ ) or octene ( $C_8H_{16}$ ), to create a graft copolymer with improved elasticity and elongation vs low density polyethylene, rendering it very suitable for stretch wrap and carrier bags. Selection of the comonomer is very important as the final polymer film can be too easy to elongate or will not elongate enough. As the number of carbon atoms in the comonomer increases, its percentage elongation increases.

Yet another example is in the comparison between general purpose polystyrene homopolymer (GPPS) and high impact polystyrene (HIPS) copolymer. The homopolymer is crystal clear, has poor oxygen and gas barrier and is very brittle. By copolymerising the styrene with butadiene, there is an improvement in impact resistance and barrier properties but a reduction in transparency. An alternative form of copolymerisation to produce styrene butadiene styrene can result in a thermoplastic elastomer (TPE) which is clear and has special properties close to those of a rubber. By copolymerising styrene with acrylonitrile to form styrene acrylonitrile, a copolymer with excellent chemical and scratch resistance and improved gas barrier can be formed. These improvements can be combined by copolymerising all three monomers together to form acrylonitrile butadiene styrene (ABS). The proportion of each constituent can be varied, allowing a range of polymers to be produced with very different properties from the starting materials. Other monomers such as methacrylic acid can be added to replace styrene, and a copolymer of methyl methacrylate, acrylonitrile and butadiene is used in film form for packaging of meat and cheese, chemicals and cosmetics. The methacrylate adds clarity, the acrylonitrile provides a good gas barrier and the butadiene imparts toughness and resistance to puncturing.

Sometimes, where copolymerisation is not possible, polymers are blended together to combine the properties of each individual polymer. An example would be polyethylene vinyl acetate (EVA) added to polyethylene to improve flexibility and adhesion properties, as used in stretch wrap film, for example.

### 12.6.7 Orientation of monomers in a copolymer

We have already discussed how different comonomers can be orientated in a copolymer. Copolymers can contain the monomer units in a completely random, alternating, block or graft format:

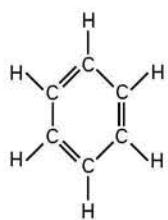
- Random copolymers, such as in the case of ethylene propylene copolymer, produce films and solid packaging forms with greater clarity, lower melt temperature and therefore a better low temperature resistance.
- Alternating copolymers, though rare, have properties associated with those that would be expected if the repeat unit were  $XO$  ( $X$  = propylene,  $O$  = ethylene).
- Block copolymer properties are quite different from those of random or alternating copolymers. For example, styrene butadiene block copolymers have a much higher impact strength than their random form, due to the elastomeric nature of the butadiene block having the ability to absorb much more energy without rupturing than a single unit, especially when paired with a brittle styrene unit. The same phenomenon occurs in ethylene propylene block copolymers which are used where impact strength is required.
- Graft copolymer properties are similar to block copolymer; for example we improve the impact strength of styrene butadiene by graft polymerisation rather than random or alternating. We can graft polymerise onto a chain formed from one monomer as previously described or onto a copolymer backbone as in the case of ABS (acrylonitrile butadiene styrene).

### 12.6.8 Forces within a polymer

Inter-atomic forces are the forces which bond atoms together to form molecules, for example carbon (C) to hydrogen (H), oxygen (O) or nitrogen (N). These forces make it possible to form very large polymer molecules containing different atoms. There are two types of inter-atomic bonds in polymers, covalent bonds and ionic bonds.

Covalent bonds, which are the more common, consist of two electrons shared by two adjacent atoms. These link atoms together by single, double or triple bonds. Aromatic structures, such as benzene (see Fig. 12.10), contain alternating double and single bonds in a cyclic formation. Polystyrene is a good example of this, where the hydrogen atom of ethylene is replaced by a benzene ring to form styrene which in turn is polymerised to polystyrene.

Sharing of electrons between dissimilar atoms is not equal. One atom having a greater affinity for the shared electron than the other results in a polar covalent bond as in PVC, where the C–Cl bond creates polarity compared to a C–C bond which would be non-polar. Ionic bonds, though rare, do occur where the affinity of two



12.10 Aromatic benzene.

Table 12.3 Inter-molecular forces and their effects on polymer properties

Intermolecular forces	Cohesive energy density	Typical polymer characteristics
Small	Low	Flexible, elastomeric behaviour, high permeability to gases, e.g. polyolefins
Medium	High	Stiffer plastic behaviour, e.g. PET
Large	Very high	High resistance to stress, high strength, good mechanical properties, low permeability to gases e.g. Polyamide (PA), ethylene vinyl alcohol (EVOH)

atoms for their shared electron is so unequal that electrons transfer from the weaker atom to the stronger, creating negative and positive ions. Oppositely charged ions attract each other. This is the mechanism by which ionomers (DuPont Surlyn®, for example, based on polyethylene) are formed. A sodium ( $\text{Na}^+$ ) or zinc ( $\text{Zn}^{2+}$ ) ion is introduced to provide some very different properties than pure polyethylene (see Chapter 13).

As molecules come together, forces are exerted by each on one another. These forces are called inter-molecular forces, i.e. between neighbouring molecules. Forces between different parts of the same molecule are referred to as intra-molecular forces. Inter-molecular forces (often called van der Waals or secondary forces) can be split into three primary categories: dispersion, induction and dipole forces. The primary forces (or bonds), namely covalent and ionic bonds, determine the molecular structure of the material, whereas the secondary forces (or bonds) are responsible for the physical nature of the molecule. Gases have the weakest secondary bonds, solids the strongest with liquids having bonds of a strength in-between the other two.

If the strength of the cohesive energy density (the energy required to distance a molecule from its neighbour so that no significant inter-molecular forces are present) is compared to the size of the inter-molecular forces, we can better understand their effect on polymer characteristics (see Table 12.3). Hydrogen bonding is a subcategory of dipole forces, their high strength and unique characteristics making them worth mentioning separately. Hydrogen bonds are an important consideration in polyamides and ethylene vinyl alcohol as can be seen in Table 12.3. (They are also very important in paper and paperboard – see Chapter 10).

Crosslinking creates bonds which have such a high bond strength that the energy to break the bond is greater than that required to decompose the polymer. Few examples

of fully crosslinked polymers are found in plastic packaging. A few closures and some adhesives, especially for lamination, utilise the performance characteristics of thermosetting plastics. Figure 12.11 shows the structure of a thermoplastic polymer (on the left), either branched as shown, or with little or no branching. Each polymer chain is unconnected with the next, compared to a thermosetting polymer (on the right), where all the polymer chains are connected by a crosslink (see Fig. 12.11).

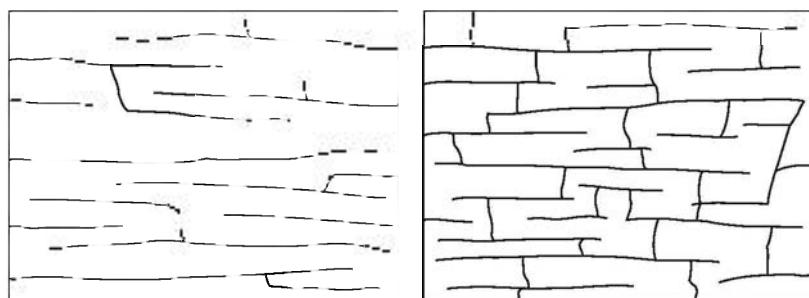
The structure of a thermosetting polymer provides some advantages and disadvantages when compared to a thermoplastic polymer.

Thermosetting polymers:

- cannot be remelted once crosslinked and therefore cannot be recycled
- have better temperature resistance
- have improved chemical and solvent resistance
- exhibit better resistance to gas and moisture permeation
- do not distort under load, unlike thermoplastics
- have a higher density than thermoplastics.

When thermoplastics are heated, the weak bonds holding the polymer chains together break, which allows the polymeric molecules to move independently of one other, resulting in them melting and being able to be formed. Once cooled in the designated form in which they have been held, for example a film or a three-dimensional moulding, the inter-molecular forces form again, holding the structure together. This can be repeated many times. Thermosetting compounds, such as phenol, melamine and urea, formaldehyde resins, are placed in the mould in a semi-polymerised state. The mould is closed and heat applied. This thermally sets the resin in the mould, due to the cross-linking of the molecules, and it cannot be remelted.

Thermoplastic elastomers (TPE) are polymers which can be processed in the same way as thermoplastics but act similarly to a thermoset elastomer such as rubber, once in the solid state. They are copolymers of rigid and elastomeric monomer units combined in such a way (graft or block) to exhibit special properties. They are rubber-like and quickly recover from deformation; add tactility to a package and, if the correct combination of comonomers is used, provide polymers with near glass-clear clarity. A good example here is styrene butadiene styrene block copolymers, which can be used for soles of shoes but also for the manufacture of clear rigid packaging, depending on the make-up of the copolymer.

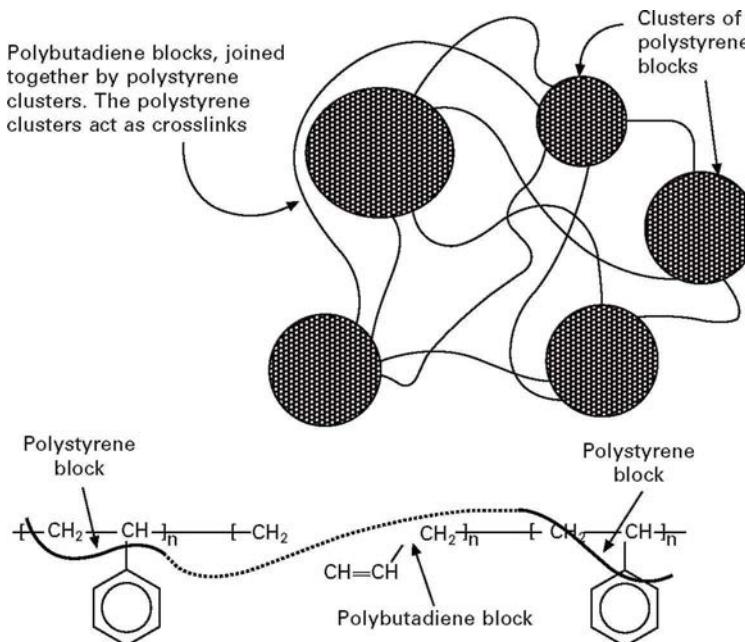


12.11 Thermosetting and thermoplastic polymers.

TPEs consist of one of six categories:

- styrene block copolymers (e.g., styrene butadiene styrene)
- polyolefin blend
- elastomeric alloys
- thermoplastic polyurethanes (TPU)
- thermoplastic copolyesters
- thermoplastic polyamides.

Styrene block copolymer TPEs are the most widely used, an example of which can be seen in Fig 12.12. The large hard, brittle styrene block sits on the flexible butadiene blocks holding them in place as if they were crosslinked. Once heat energy is applied to the monomer, the forces holding everything in place are broken and the molecules move freely. When the polymer is in its solid state, the held elastomeric butadiene chains have very good elastomeric properties providing very good resilience to the clear polymer. Such polymers are being developed for film and mouldings where they are both beneficial and affordable. Cosmetic and toiletry bottles and jars, films (e.g. for cling film), providing glass clarity, tactility and improved barrier and mechanical properties can all be manufactured from thermoplastic elastomers.



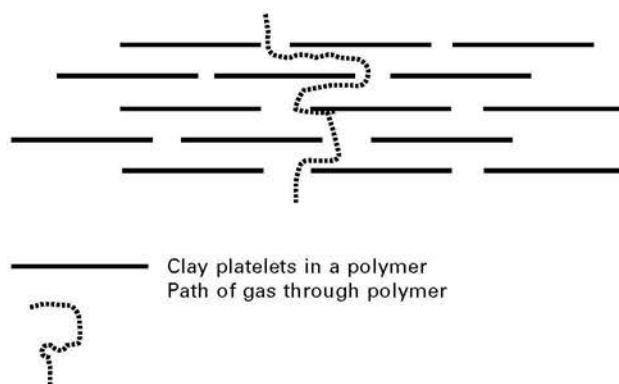
12.12 An example of a styrene block copolymer TPE: poly(styrene-butadiene-styrene), otherwise known as SBS rubber.

### 12.6.9 Additives

The majority of polymers used to manufacture plastic packaging are thermoplastic. If not compounded with process aids and functional additives, thermoplastics would

have a much shorter usage life than they actually do. Additives used in the processing of thermoplastic polymers are:

- Antioxidants, which help to prevent deterioration of the polymer chain as a result of oxidation. They can sometimes cause yellowing of the polymer surface.
- UV stabilisers and inhibitors, which help to slow down the deterioration of the polymer by protecting it from UV light.
- Slip agents, which control the amount of slip (coefficient of friction (CoF)), by blooming to the surface. This can take up to 72 hours before it becomes effective consistently.
- Antistatic agents, which provide a surface which attracts fine droplets of water thus dissipating any build-up of static electricity which would attract dust particles.
- Colours, which are used to decorate and help brand the product. They may also protect against UV and natural light, e.g., carbon black. They are added as a solid or liquid masterbatch (see Chapter 14).
- Fillers, which can be added for special effects, e.g. mica to provide shiny particles, china clay to reduce the cost or glass fibre to improve physical strength. If the filler is added in a very orderly manner and the size of the filler particle is of nano proportions (approx.  $200 \times 10^{-9}$  m), it can increase a polymer's barrier to gasses by diverting the gas around the filler particles, thus increasing the length it has to travel through the polymer (see Fig. 12.13).

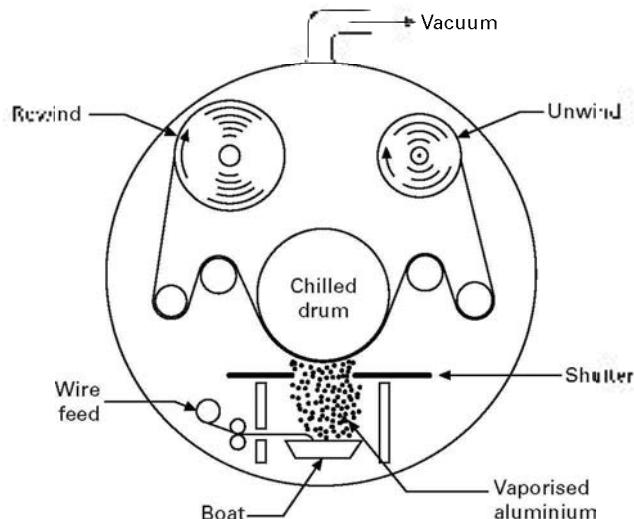


12.13 Nano fillers for improved gas barrier.

#### 12.6.10 Special treatments of polymeric materials

We have already discussed the need to treat the surface of certain polymers (e.g., polyolefins) to ensure there is enough energy to adhere sufficiently to addition of adhesive, coatings and print. There are other special treatments used either for aesthetic purposes or to improve properties. Vacuum deposition of metals and metal oxides on the surface of polymer films increases both gas and moisture vapour barrier as well as reducing the amount of UV light that can pass through the film. The usual materials used for vacuum deposition are aluminium metal, aluminium oxide or silicon oxide. A typical use for a film with an aluminium metal coating is high

fat snack products; a bag of potato crisps or chips requires a moisture vapour, gas and UV barrier to prevent the product going rancid and soft (Fig. 12.14). Vacuum deposition can also be carried out on three-dimensional mouldings, for example a clear coating of silicon oxide deposited on plastic bottles for beer and soft drinks, to improve oxygen barrier, and a metallic coating on plastic cosmetic compacts to give the more expensive appearance of metal.



12.14 Addition vacuum deposition chamber.

### 12.6.11 Mixing polymers

Polymers can be mixed together to form a cohesive mix, as discussed earlier in this chapter. However, if we want to gain the maximum effect, we can combine polymers together in a more orderly fashion. We can coextrude or coinject different polymers together, creating individual layers, which enables us to use the combination of the properties of the individual monomers; for example EVOH has excellent gas barrier but is adversely affected by moisture, PP has excellent moisture barrier but no effective gas barrier. If we combine the two polymers together we get a film or moulding with excellent gas and moisture barrier (see Chapter 14 for details).

Special coextrusions are also effective in improving the heat seal, anti-fogging and cling properties of polymer films. In the modern world of technical advancement, it is unlikely that a polymer film will consist of a single extrusion. Coextrusion is too advantageous to ignore. One important advantage is that the waste material from a conversion process can be incorporated in the middle layers of a film or moulding, thus avoiding costly waste and environmental damage.

### 12.6.12 Physical orientation of polymers

Mechanical and barrier properties of a polymer can also be improved by stretching the polymer chains of a film or a moulding, in one or both directions. This is carried out

at the melting temperature of the polymer. It stretches and aligns the polymer chains, providing improved physical (tear strength, tensile strength, reduced stretch, better clarity, etc.) and chemical (improved gas and moisture barriers) properties but may have an adverse effect on the heat sealing range of a film, as for polypropylene.

Polymer properties of the common packaging polymers are discussed in Chapter 9.

## 12.7 Sources of further information and advice

- Baner, A.L. and Piringer, O. (2008) *Plastic Packaging Materials for Food*. Wiley, New York.
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- 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](http://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>

# 13

## Plastics properties for packaging materials

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**Abstract:** This chapter presents a review of the properties and uses of the common packaging plastics, and some of the materials used for specialist applications.

**Key words:** plastics packaging market, tensile strength, elongation, tear strength, impact strength, surface friction, viscoelasticity, transparency, chemical stability, environmental stress cracking, barrier properties, glass transition temperature, melting temperature, heat sealability, density, polyethylene family, ethene, low density polyethylene, linear low density polyethylene, high density polyethylene, metallocene, collation shrink film, pallet shrink film, pallet stretch film, stretch hooding, ethylene vinyl acetate, plastic sacks, ethylene vinyl alcohol, polyvinyl acetate, polyvinyl alcohol, ethylene acrylic acid, ionomers, polypropylene, isotactic, atactic, syndiotactic, nucleating agents, biaxial orientation, thin wall containers, cast polypropylene, polarity, polyvinyl chloride, polyvinylidene chloride, plasticiser, polystyrene, general purpose styrene, high impact polystyrene, expanded polystyrene, polyethylene terephthalate, polyethylene terephthalate glycol, polyethylene naphthalate, styrene copolymers, styrene acrylonitrile, acrylonitrile butadiene styrene, Barex®, polyamide, nylon, polycarbonate, fluoropolymers, thermoplastic elastomers, cyclic olefin copolymers, liquid crystal polymers, thermosets, phenol formaldehyde, urea formaldehyde, cellulose film, cellulose acetate, bio-based polymers, biodegradation, biomass, oxodegradable, starch-based polymers, cellulose-based polymers, polylactic acid, polyhydroxyalkanoates.

### 13.1 Introduction

Plastics are an essential part of modern life. Major industries depend on them and products as varied as cars, aeroplanes, electronic equipment, textiles, furniture, household goods, jewellery, shoes and clothing all use increasing quantities of plastics in their construction. Plastics used in packaging are just as widespread, from the commonly used plastic bottles and caps for milk and soft drinks, to the films used to pack a range of goods such as bacon, confectionery, nuts and bolts and textiles, and the rigid boxes/cases used for CDs and computer games. This chapter follows on from the basic principles of polymer chemistry discussed in Chapter 12, and it is essential to refer back to it when working through this chapter. Of particular importance is the section on factors affecting the characteristics of polymers, as this contains many examples relevant to individual material properties discussed here.

### 13.2 Market overview

Plastic is the most rapidly expanding sector of packaging materials, despite being the newcomer when one reviews historical development. From Table 13.1 it can be

Table 13.1 Overview of the development of plastics

Date	Material
1907	Phenol formaldehyde ('Bakelite') thermosetting resins
1927	Polyvinyl chloride (PVC)
1927	Cellulose acetate
1936	Polyvinyl acetate (PVA)
1938	Polystyrene (PS)
1938	Nylon 66
1939	Polyvinylidene chloride (PVdC)
1941	Polytetrafluoroethylene (PTFE)
1942	Low density polyethylene (LDPE)
1944	Polyethylene terephthalate (PET)
1948	Acrylonitrile butadiene styrene (ABS)
1955	High density polyethylene (HDPE)
1957	Polypropylene (PP)
1957	Polycarbonate (PC)
1960	Linear low density polyethylene (LLDPE)
1964	Ionomers, e.g. Surlyn
1970	Thermoplastic elastomers (TPEs)
1972	Ethylene vinyl alcohol (EVOH)
1994	Polyethylene naphthalate (PEN)

Table 13.2 European polymer demand for packaging vs. other markets, 2007 (000s tonnes)

Material	Packaging	Other markets	Packaging as % of total market
Low density/linear low density polyethylene	5,976	3,110	66
High density polyethylene	3,357	2,609	56
Polypropylene	3,414	5,789	37
Polyvinyl chloride	748	5,707	12
Polystyrene	1,511	2,218	68
Polyethylene terephthalate	3,096	147	95
Other	132	3,084	4
Total	18,204	22,664	45

Source: Applied Market Information Ltd ([www.amiplastics.com](http://www.amiplastics.com)).

seen that the first plastics were developed in the early years of the twentieth century. However, it was not until the 1950s that their use became widespread, when the relatively low cost polyethylenes brought plastics out of specialist applications and into the mass market. These 'new' materials became increasingly popular due to their ready availability (made from by-products of the oil industry); easy processability (most of those listed in Table 13.1 are thermoplastics, which soften at relatively low temperatures compared with materials such as glass and metal, and are easy to form into a range of different shapes); and the ability to tailor their properties closely to the intended end use, leading to a wide range of market applications.

Packaging is not the only market for plastics, but it is certainly a significant one. Table 13.2 shows the European market for plastics in packaging was just over 18 million