1 Paper and paperboard – raw materials, processing and properties

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1.1 Introduction – quantities, pack types and uses

Paper and paperboard are manufactured worldwide. The world output for the years quoted is shown in Table 1.1. The trend has been upward for many years; indeed, worldwide production has more than doubled in just three decades. Both materials are produced in all regions of the world. The proportions produced per region in 2010 are shown in Table 1.2.

Paper and paperboard have many applications. These include newsprint, books, tissues, stationery, photography, money, stamps, general printing, etc. The remainder comprises packaging and many industrial applications, such as plasterboard base and printed impregnated papers for furniture. In 2010, paper and paperboard produced for packaging applications accounted for 51% of total paper and paperboard production (BIR, 2011).

A single set of figures for world production of paper and paperboard hides a very significant change that has taken place in the last decade. A large amount of investment has poured into Asia, resulting in the creation of many new mills with large and fast machines. Consequently, the proportion of world production originating from Asia has increased by 10% since 2003; Europe and North America have been the casualties, and both regions have experienced significant numbers of mill closures during this period.

As a result of the widespread uses of paper and paperboard, the apparent consumption of paper and paperboard per capita can be used as an economic barometer, i.e. indication, of the standard of economic life. The apparent consumption per capita in the various regions of the world in 2010 is shown in Table 1.3.

The manufacture of paper and paperboard is therefore of worldwide significance and that significance is increasing. A large proportion of paper and paperboard is used for packaging purposes. About 30% of the total output is used for corrugated and solid fibreboard, and the overall packaging usage is significant. Amongst the membership of CEPI (Confederation of European Paper Industries), 43% of all paper and paperboard output during 2011 was used in packaging, (CEPI, 2011).

Not only is paper and paperboard packaging a significant part of the total paper and paperboard market, it also provides a significant proportion of world *packaging* consumption.

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Table 1.1 World production of paper and paperboard

Year	Total tonnage (million tonnes)
1980	171
1990	238
2000	324
2005	367
2006	382
2007	394
2008	391
2009	371
2010	394

Source: BIR (2010).

Table 1.2 World production % of paper and paperboard by region for 2010

Region	% of world production
Europe	27.1
Latin America	5.2
North America	22.5
Africa	1.1
Asia	43.1
Australasia	1.0

Source: BIR (2010).

Table 1.3 Apparent per capita consumption of all types of paper and paperboard in 2010

Location	Apparent consumption (kg)
North America	234.8
Europe	142.0
Australasia	135.0
Latin America	45.5
Asia	40.0
Africa	7.8

Source: BIR (2010).

Up to 40% of all *packaging* is based on paper and paperboard, making it the largest packaging material used, by weight. Paper and paperboard packaging is found wherever goods are produced, distributed, marketed and used.

Many of the features of paper and paperboard used for packaging, such as raw material sourcing, principles of manufacture, environmental and waste management issues, are identical to those applying to all the main types of paper and paperboard. It is therefore important to view the packaging applications of paper and paperboard within the context of the worldwide paper and paperboard industry.

According to Robert Opie (2002), paper was used for wrapping reams of printing paper by a papermaker around 1550; the earliest printed paper labels were used to identify bales of cloth in the sixteenth century; printed paper labels for medicines were in use by 1700 and paper labels for bottles of wine exist from the mid-1700s. One of the earliest references to the use of paper for packaging is in a patent taken out by Charles Hildeyerd on 16 February 1665 for 'The way and art of making blew paper used by sugar-bakers and others' (Hills, 1988). For an extensive summary of packaging from the 1400s using paper bags, labels, wrappers and cartons, see Davis (1967).

The use of paper and paperboard packaging accelerated during the latter part of the nineteenth century to meet the developing needs of manufacturing industry. The manufacture of paper had progressed from a laborious manual operation, one sheet at a time, to continuous high-speed production with wood pulp replacing rags as the main raw material. There were also developments in the techniques for printing and converting these materials into packaging containers and components and in mechanising the packaging operation.

Today, examples of the use of paper and paperboard packaging are found in many places, such as supermarkets, traditional street markets, shops and departmental stores, as well as for mail order, fast food, dispensing machines, pharmacies, and in hospital, catering, military, educational, sport and leisure situations. For example, uses can be found for the packaging of:

- dry food products – for example cereals, biscuits, bread and baked products, tea, coffee, sugar, flour and dry food mixes
- frozen foods, chilled foods and ice cream
- liquid foods and beverages – milk, wines and spirits
- chocolate and sugar confectionery
- fast foods
- fresh produce – fruits, vegetables, meat and fish
- personal care and hygiene – perfumes, cosmetics and toiletries
- pharmaceuticals and health care
- sport and leisure
- engineering, electrical and DIY
- agriculture, horticulture and gardening
- military stores.

Papers and paperboards are sheet materials comprising an overlapping network of cellulose fibres that self-bond to form a compact mat. They are printable and have physical properties which enable them to be made into various types of flexible, semi-rigid and rigid packaging.

There are many different types of paper and paperboard. Appearance, strength and many other properties can be varied depending on the type(s) and amount of fibre used, and how the fibres are processed in fibre separation (pulping), fibre treatment and in paper and paperboard manufacture.

In addition to the type of paper or paperboard, the material is also characterised by its weight per unit area and thickness. Indeed, the papermaking industry has many specific terms, and a good example is the terminology used to describe weight per unit area and thickness.

Weight per unit area may be described as 'grammage' because it is measured in grammes per square metre (g m^{-2}). Other area/weight-related terms are 'basis weight' and 'substance', which are usually based on the weight in pounds of a stated number of sheets of specified dimensions, also known as a 'ream', for example 500 sheets of 24 in. × 36 in., which equates to total ream area of 3000 ft^2. The American organisation TAPPI (Technical Association of the Pulp & Paper Industry, 2002–2003) issues a standard that describes basis weight in great detail; currently there are 14 different areas used for measurement, depending upon the grade being measured. It is therefore important when discussing weight per unit area, as with all properties, to be clear as to the methods and units of measurement.

Thickness, also described as ‘caliper’, is measured either in microns (μm), 0.001 mm or in thou. (0.001 in.), also referred to as *points*.

Appearance is characterised by the colour and surface characteristics, such as whether it is smooth or rough and has a high gloss, satin or matte finish.

Paperboard is thicker than paper and has a higher weight per unit area, although the dividing line between the two is somewhat blurred. Paper over 225 g m^{-2} is defined by ISO (International Organization for Standardization) as paperboard, board or cardboard. Some products are, however, known as paperboard even though they are manufactured at lower grammages; for example, many producers and merchants now class products of 180–190 g m^{-2} upwards as paperboard, because improvements in manufacturing techniques mean these lightweight materials can now be produced with similar strength properties to older heavyweight grades.

The main types of paper and paperboard-based packaging are:

- bags, wrappings and infusible tissues, for example tea and coffee bags, sachets, pouches, overwraps, sugar and flour bags, and carrier bags
- multiwall paper sacks
- folding cartons and rigid boxes
- corrugated and solid fibreboard boxes (transit or shipping cases)
- paper-based tubes, tubs and composite containers
- fibre drums
- liquid packaging
- moulded pulp containers
- labels
- sealing tapes
- cushioning materials
- cap liners (sealing wads) and diaphragms (membranes).

Paper and paperboard-based packaging is widely used because it meets the criteria for successful packing, namely to:

- contain the product
- protect goods from mechanical damage
- preserve products from deterioration
- inform the customer/consumer
- provide visual impact through graphical and structural designs.

These needs are met at all three levels of packaging, namely:

- primary – product in single units at the point of sale or use, for example cartons
- secondary – collections of primary packs grouped for storage and distribution, wholesaling and ‘cash and carry’, for example transit trays and cases
- tertiary – unit loads for distribution in bulk, for example heavy-duty fibreboard packaging.

Paper and paperboard, in many packaging forms, meet these needs because they have appearance and performance properties which enable them to be made into a wide range of packaging structures cost-effectively. They are printable, varnishable and can be laminated to other materials. They have physical properties which enable them to be made into flexible, semi-rigid and rigid packages by cutting, creasing, folding, forming, winding, gluing, etc.

Paper and paperboard packaging is used over a wide temperature range, from frozen-food storage to the temperatures of boiling water and heating in microwave and conventional ovens.

Whilst it is approved for direct contact with many food products, packaging made solely from paper and paperboard is permeable to water, water vapour, aqueous solutions and emulsions, organic solvents, fatty substances (except grease-resistant papers), gases such as oxygen, carbon dioxide and nitrogen, aggressive chemicals, and volatile vapours and aromas. Whilst paper and paperboard can be sealed with several types of adhesive, with certain special exceptions, such as tea-bag grades, it is not itself heat sealable.

Paper and paperboard can acquire barrier properties and extended functional performance, such as heat sealability, heat resistance, grease resistance, product release, etc., by coating, lamination and impregnation. Traditional materials used for these purposes include:

- extrusion coating with polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET or PETE), ethylene vinyl alcohol (EVOH) and polymethyl pentene (PMP)
- lamination with plastic films or aluminium foil
- treatment with wax, silicone or fluorocarbon
- impregnated with a vapour-phase metal-corrosion inhibitor, mould inhibitor or coated with an insect repellent.

Recently, the use of various biopolymers has gained predominance because their use does not impede biodegradation of treated paper or paperboard. Biopolymers based upon proteins (casein and caseinates, whey, soy, wheat gluten or corn zein), polysaccharides (chitosan, alginate or starch) and lipids (long chain fatty acids and waxes) have all been used, singularly or in combination, to form barriers against gases, water vapour or grease. Furthermore, these coatings can be rendered bioactive by addition of natural antimicrobial agents, such as lactic acid, nisin, carvacrol or cinnamaldehyde (Khwaldia et al., 2010).

Packaging made solely from paperboard can also provide a wide range of barrier properties by being *overwrapped* with a heat-sealable plastic film, such as polyvinylidene chloride (PVdC), coated oriented polypropylene (OPP or, as it is sometimes referred to, BOPP) or regenerated cellulose films, such as Cellophane™.

Several types of paper and paperboard-based packaging may incorporate metal or plastic components, examples being as closures in liquid-packaging cartons and as lids, dispensers and bases in composite cans.

In an age where environmental and waste management issues have a high profile, packaging based on paper and paperboard has important advantages:

- The majority of paper-based packaging grades are now produced using recovered fibre. As such, paper and paperboard packaging forms a very important end product for the recovered paper sector.
- The main raw material (wood or other suitable vegetation) is based on a naturally renewable resource. In most cases it is sustainably sourced from certified plantations.
- The growth of these raw materials removes carbon dioxide from the atmosphere, thereby reducing the greenhouse effect. As such they have a smaller carbon footprint than materials made from non-renewable resources, such as petrochemical derivatives.

- When the use of the package is completed, most types of paper and paperboard packaging can be recovered and recycled. Furthermore, they can all be incinerated with energy recovery, and if none of these options is possible, most are biodegradable in landfill.

1.2 Choice of raw materials and manufacture of paper and paperboard

1.2.1 Introduction to raw materials and processing

So far we have indicated that paper and paperboard-based packaging provides a well-established choice for meeting the packaging needs of a wide range of products. We have defined paper and paperboard and summarised the reasons why this type of packaging is used. We now need to discuss the underlying reasons why paper and paperboard packaging is able to meet these needs.

This discussion falls into four distinct sections:

- choice and processing of raw materials
- manufacture of paper and paperboard
- additional processes which enhance the appearance and performance of paper and paperboard by coating and lamination
- use of paper and paperboard in the printing, conversion and construction of particular types of packaging.

Cotton, wool and flax are examples of fibres and we know that they can be spun into a thread and that thread can be woven into a sheet of cloth material. Papers and paperboards are also based on fibre, but the sheet is a three-dimensional self-bonded structure formed by random overlapping of fibres. The resulting structure, which is known as a *sheet* or *web*, is sometimes described as being 'non-woven'. The fibres are prepared by mixing them with water to form a very dilute suspension, which is poured onto a porous mesh. The paper structure forms as an even layer on this mesh, which is known as a wire and which acts as a sieve. Most of the water is then removed successively by drainage, pressure and heat.

So why does this structure have the strength and toughness which makes it suitable for printing and conversion for use in many applications, including packaging? To answer this question we need to examine the choices which are available in the raw materials used and how they are processed.

According to tradition, paper was first made in China around the year AD 105 using fibres such as cotton and flax. Such fibres are of vegetable origin, based on cellulose, which is a natural polymer, formed in green plants and some algae from carbon dioxide and water by the action of sunlight. The process initially results in natural sugars based on a multiple-glucose-type structure comprising carbon, hydrogen and oxygen in long chains of hexagonally linked carbon atoms, to which hydrogen atoms and hydroxyl (OH) groups are attached. This process is known as photosynthesis; oxygen is the by-product and the result is that carbon is removed (fixed) from the atmosphere. Large numbers of cellulose molecules form fibres – the length, shape and thickness of which vary depending on the plant species concerned. Pure cellulose is non-toxic, tasteless and odourless.

The fibres can bond at points of interfibre contact as the fibre structure dries during water removal. It is thought that bonds are formed between hydrogen (H) and OH units in adjacent cellulose molecules causing a consolidation of the three-dimensional sheet structure. The degree of bonding, which prevents the sheet from fragmenting, depends on a number of factors which can be controlled by the choice and treatment of the fibre prior to forming the sheet.

The resulting non-woven structure which we know as paper ultimately depends on a three-dimensional overlapped fibre network and the degree of interfibre bonding. Its thickness, weight per unit area and strength can be controlled, and in this context paperboard is a uniform thicker paper-based sheet. It is flat, printable, creasable, foldable, gluable and can be made into many two- and three-dimensional shapes. These features make paper and paperboard ideal wrapping and packaging materials.

Over the centuries, different cellulose-based raw materials, particularly rags incorporating cotton, flax and hemp, were used to make paper, providing good examples of recycling. During the nineteenth century, the demand for paper and paperboard increased, as wider education for the increasing population created a rising demand for written material. This in turn led to the search for alternative sources of fibre. Esparto grass was widely used but eventually processes for the separation of the fibres from wood became technically and commercially successful and from that time (1880 onwards) wood has become the main source of fibre. The process of fibre separation is known as pulping.

Today there are choices in:

- source of fibre
- method of fibre separation (pulping)
- whether the fibre is whitened (bleached) or not
- preparation of the fibre (stock) prior to use on the paper or paperboard machine.

1.2.2 Sources of fibre

Basically, the choice is between *virgin*, or primary, fibre derived from vegetation, of which wood is the principal source, and *recovered*, or secondary, fibre derived from waste paper and paperboard. Until 2005, virgin pulp formed the main fibre source for paper manufacture. Since that date, recovered paper has become the principal fibre used worldwide (BIR, 2006). In 2010, about 45% of the fibre used worldwide was virgin fibre and the rest, 55%, was from recovered paper. It must be appreciated at the outset that:

- fibres from all sources, virgin and recovered, are not universally interchangeable with respect to the paper and paperboard products which can be made from them
- some fibres by nature of their use are not recoverable and some that are recovered are not suitable for recycling on grounds of hygiene and contamination
- fibres cannot be recycled indefinitely.

The properties of virgin fibre depend on the species of tree from which the fibre is derived. The flexibility, shape and dimensional features of the fibres influence their ability to form a uniform overlapped network. Some specialised paper products incorporate other cellulose fibres such as cotton, hemp, or bagasse (from sugar cane), and there is also some use of synthetic fibre.

The paper or paperboard maker has a choice between trees which have relatively *long* fibres, such as spruce, fir and pine (*coniferous species*), which provide strength, toughness

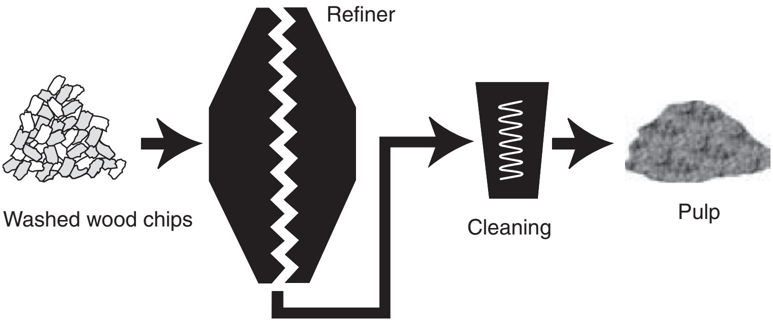

Figure 1.1 Production of mechanically separated pulp. (Courtesy of Pro Carton.)

and structure, and *shorter* fibres, such as those from birch, eucalyptus, poplar (aspen), acacia and chestnut (*deciduous species*), which give high bulk (low density), closeness of texture and smoothness of surface.

The long, wood-derived fibres used by the paper and paperboard industry are around 3–4 mm in length and the short fibres are 1–1.5 mm. The fibre tends to be ribbon shaped, about 30 microns across and therefore visible to the naked eye.

The terms 'long' and 'short' are relative to the lengths of fibres from wood as, by contrast, cotton and hemp fibres may be as long as 20–30 mm.

1.2.3 Fibre separation from wood (pulping)

In trees, the cellulose fibres are cemented together by a hard, brittle material known as lignin, another complex polymer, which forms up to 30% of the tree. The separation of fibre from wood is known as pulping. The process may be based on either mechanical or chemical methods.

Mechanical pulping applies mechanical force to wood in a crushing or grinding action, which generates heat and softens the lignin thereby separating the individual fibres. As it does not remove lignin, the yield of pulp from wood is very high. The presence of lignin on the surface and within the fibres makes them hard and stiff. They are also described as being dimensionally more stable. This is related to the fact that cellulose fibre absorbs moisture from the atmosphere when the relative humidity (RH) is high and loses moisture when the RH is low – a process that is accompanied by dimensional changes, the magnitude of which is reduced if the fibre is coated with a material such as lignin. The degree of interfibre bonding with such fibres is not high, so sheets tend to be weak. Products made from mechanically separated fibre have a 'high bulk' or low density, i.e. a relatively low weight per unit area for a given thickness. This, as will be discussed later, has technical and commercial implications. Figure 1.1 illustrates the production of mechanically separated pulp.

The most basic form of mechanical pulping, which is still practised in some mills today, involves forcing a debarked tree trunk against a rotating grinding surface. This process uses a large amount of energy and results in a very high-yield product known as stone groundwood (SGW) pulp. Alternatively, lignin can be softened using heat or by the action of certain chemicals; this reduces the mechanical energy needed to separate fibres during pulping and reduces fibre damage, leading to higher quality pulp. Wood in chip form may be heated prior

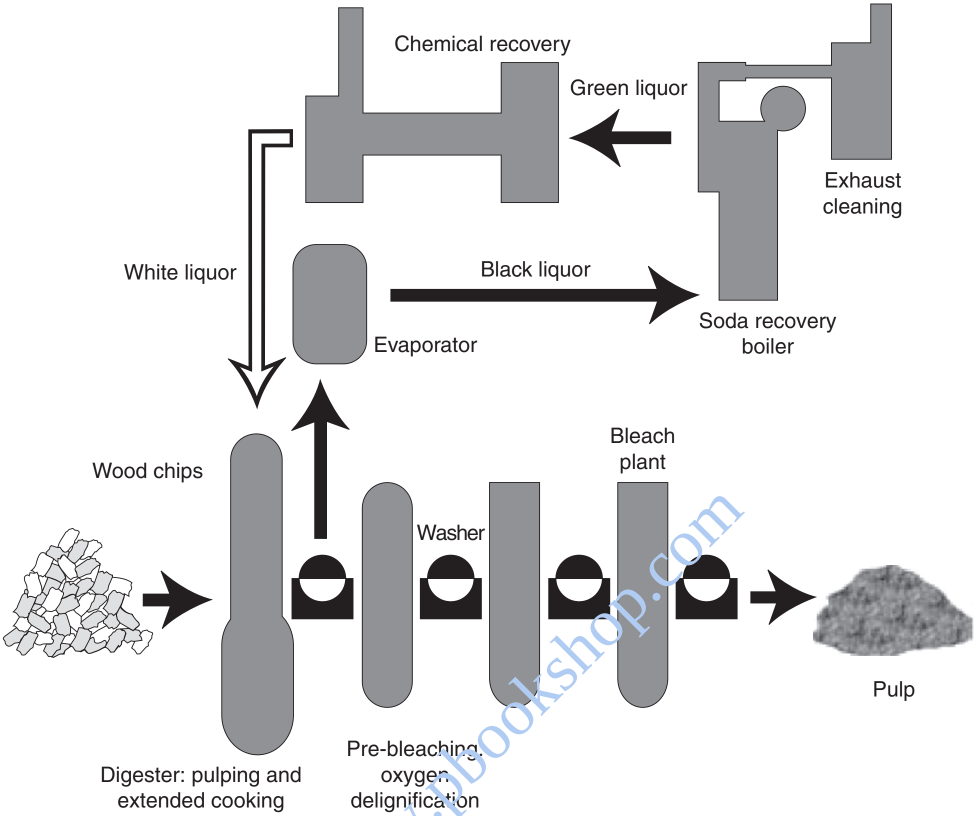

Figure 1.2 Production of chemically separated bleached pulp. (Courtesy of Pro Carton.)

to or during pulping, in which case the pulp is known as thermomechanical pulp (TMP); application of chemicals such as sodium sulphite, sodium hydroxide or oxalic acid yields chemimechanical pulp (CMP); and when the two processes are combined, the resulting pulp is called chemi-thermomechanical pulp (CTMP). Mechanical pulp retains the colour of the original wood although CTMP is lighter in colour because more lignin is removed.

Chemical pulping uses chemicals to separate the fibre by dissolving the non-cellulose and non-fibrous components of the wood (Fig. 1.2). There are two main processes characterised by the names of the types of chemicals used. The sulphate, or Kraft, process uses strong alkali; it is most widely used today because it can process all the main types of wood, and the chemicals can be recovered and reused. The other main process is known as the sulphite process, which uses strong acid. In both processes, the non-cellulose and non-fibrous material extracted from the wood is used as the main energy source in the pulp mill and in what are referred to as 'integrated' mills, which manufacture both pulp and paper/paperboard on the same site.

Chemically separated pulp comprises 74% of virgin wood fibre production. It has a lower yield than the mechanically separated pulp due to the fact that the non-cellulose constituents of the wood have been removed. This results in pulp which can undergo a high degree of interfibre bonding. Furthermore, the average fibre length of wood from

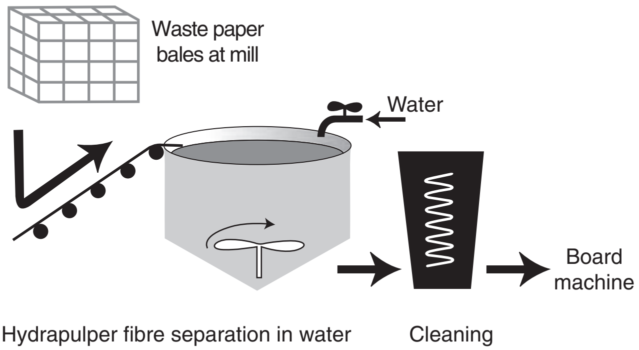

Figure 1.3 Production of pulp from recovered paper/board (recycling). (Courtesy of Pro Carton.)

the same species is longer than for mechanically separated fibre. It is also more flexible. These factors result in a stronger and more flexible sheet. The colour is brown.

1.2.4 Whitening (bleaching)

Chemically separated pulp can be whitened or bleached by processes which remove residual lignin and traces of any other wood-based material. Bleached pulp is white in colour even though individual cellulose fibres are colourless and translucent. Chemically separated and bleached fibre is pure cellulose, and this has particular relevance in packaging products where there is a need to prevent materials originating from the packaging affecting the flavour, odour or aroma of the product. Examples of such sensitive products are chocolate, butter, tea and tobacco.

Bleaching has been subject to criticism on environmental grounds. This was due to chloro-organic by-products in the effluent from mills where chlorine gas was used to treat the pulp. The criticism is no longer valid, as today the main bleaching process is elemental chlorine free (ECF) which uses oxygen, hydrogen peroxide and chlorine dioxide. The by-products of this process are simple and harmless. Another process called totally chlorine free (TCF) is based on oxygen and hydrogen peroxide. Ozone is also becoming an increasingly common and powerful bleaching agent that is being incorporated into both TCF and ECF processes (Métais et al., 2011).

Bleached cellulose fibre has high light stability, i.e. the tendency for fading or yellowing in sunlight is much reduced.

1.2.5 Recovered fibre

Waste paper and paperboard are also collected, sorted and repulped by mechanical agitation in water (Fig. 1.3). There are many different qualities of repulped fibre depending on the nature of the original fibre, how it was processed and how the paper or paperboard product was converted and used. Each time paper or paperboard is repulped, the average fibre length and the degree of interfibre bonding is reduced. This, together with the fact that some types of paper and paperboard cannot be recovered by nature of their use, means that new or virgin fibre, made directly from primary vegetation such as wood, must be introduced into the market on a regular basis to maintain *quantity* and *quality*.

There are many classifications, based on type and source, of recovered paper and paperboard which reflect their value for reuse. Classifications range from ‘white shavings’ (highly priced), newspapers (medium priced) to ‘mixed recovered paper and board’ (lowest priced). Generally, where recovered paper and paperboard which are printed are used in the manufacture of packaging grades, they are not de-inked as part of the process. Industry-agreed classification lists have been developed in Europe, where EN643 (2001) categorises 67 defined grades; the USA and Japan both have similar grading systems.

Some paper and paperboard products are either made exclusively from recycled pulp or contain a high proportion of recycled fibre. Others are made exclusively from either chemical pulp or a mixture of chemical and mechanical pulp.

1.2.6 Other raw materials

In addition to fibre, which constitutes around 89% of the raw material used for paper and paperboard, there are a number of non-fibrous additives (Zellcheming, 2008). These comprise:

- mineral pigments used for surface coatings or as fillers
- internal sizing additives
- strength additives
- surface sizing additives
- chemicals used to assist the process of paper manufacture.

They all assist in one way or another in improving either the appearance or performance of the product or the productivity of the process.

Coating the paper or paperboard involves the application of one or more layers of mineral pigment to one or both surfaces. Coatings control surface appearance, smoothness, gloss, colour (usually whiteness) and printability. Coatings comprise a pigment, generally of china clay, calcium carbonate (chalk) or titanium dioxide; an adhesive or binder, which ensures the particles both adhere together and to the surface being coated; and water (the vehicle), which facilitates the application and smoothing of the wet coating. Additional components could be optical brightening agents (OBA), also known as fluorescent whitening agents (FWA), dyes and processing aids such as anti-foaming agents.

Fillers are white inorganic materials, similar to pigments used in coatings but of larger particle size, added to the stock during paper manufacture. They fill voids in the fibre structure and increase light scattering, improving the smoothness and printability of the surface and also the opacity and shade of uncoated papers. In general, fillers are not widely used in the manufacture of packaging grades of paper and paperboard.

Mineral pigment used for coating and as fillers account for 8% of the raw materials used by the paper industry.

Internal sizing is the technique whereby the surfaces of cellulose fibres which are naturally absorbent to water are treated to render them water repellent. Traditionally, this has been carried out by what is known as alum sizing. The material used comprises a rosin size derived from pine tree gum which, after treatment to make it water soluble, is added together with aluminium sulphate at the stock-preparation stage – hence the name ‘alum’. The aluminium sulphate reacts with rosin to produce a modified resin soap which is deposited onto the fibre surface. The process has been progressively developed using both rosin and chemically unrelated synthetic resins.

Alum sizing still accounted for around 30% of the world market in 2005. However, most internal sizing is performed using alkyl ketene dimer (AKD), a waxy substance, alkenyl succinic anhydride (ASA) or other synthetic sizing agents.

Resins, such as urea-formaldehyde (UF), melamine-formaldehyde (MF) and polyamide-epichlorohydrin (PAE) can be added to ensure that a high proportion of the dry strength of paper is retained when it is saturated with water, as would be necessary for multiwall paper sacks which may be exposed to rain, or carriers for cans or bottles of beer in the wet environment of a brewery. Starch is used to increase strength by increasing interfibre bonding within the sheet and interply bonding in the case of multi-ply paperboard.

Starch is also applied as a *surface size* in the drying section of a paper or paperboard machine to one or both surfaces. The purpose is to increase the strength of the sheet and in particular the surface strength which is important during printing. It helps to bind the surface fibres into the surface, thereby preventing fibre shedding, which would lead to poor printing results. It also prepares the surface for mineral pigment coating. Other additives used to modify performance include wax (resistance to moisture, permeation of taint and odour, heat sealability and gloss), acrylic resins (moderate moisture resistance) and fluorocarbons (grease resistance).

Various other chemicals are used to assist the process of manufacture. Examples are anti-foaming agents, flocculating agents to improve drainage during the forming of the wet sheet, biocides to restrict microbiological activity in the mill and pitch-control chemicals which prevent pitch (wood resins) from being deposited on the paper machine where it can build up and break away causing machine web breaks and subsequent problems with particles (fragments) in printing. Some of the newer chemicals are based upon the use of renewable feedstock in place of petrochemicals (Greenall and Bloembergen, 2011), and the use of nanotechnology is also becoming increasingly common (Patel, 2009).

1.2.7 Processing of fibre at the paper mill

Preparing fibres for paper manufacture is known as ‘stock preparation’. The properties of fibres can be modified by processing and the use of additives at the stock-preparation stage prior to paper or paperboard manufacture. In this way, the papermaker can in theory start with, for example, a suspension of bleached chemically separated fibre in water, and by the use of different treatments produce modified pulps which can be used to make grades as diverse as blotting paper, bag paper or greaseproof paper.

The surface structure of the fibre can be modified in a controlled way by mechanical treatment in water. This was originally performed in a beater. Beating is a *batch* process in which the pulp suspension is drawn between moving and stationary bars. The moving bars are mounted on the surface of a beater roll which rotates at a fixed, adjustable distance above a bedplate, which also carries bars. The motion of the beater roll draws the suspension between the bars causing fibrillation of the fibre surface and swelling of the fibre. The suspension is thrown over the backfall and around the midfeather to the front of the roll for further treatment as shown in the illustration from the Paper Industry Technical Association, (PITA), (Fig. 1.4). Today, unless the grade of paper being produced requires beating in this way, for example greaseproof paper, where the pulp is highly beaten to an almost gelatinous consistency (Fig. 1.5), this treatment is carried out as a continuous, *in-line*, process through a refiner. Refiners also have stationary and moving bars, mounted either conically or on parallel discs (Grant et al., 1978).

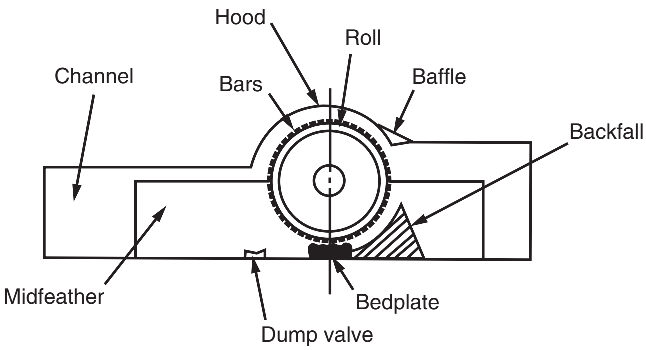

Figure 1.4 Beater. (Courtesy of PITA.)

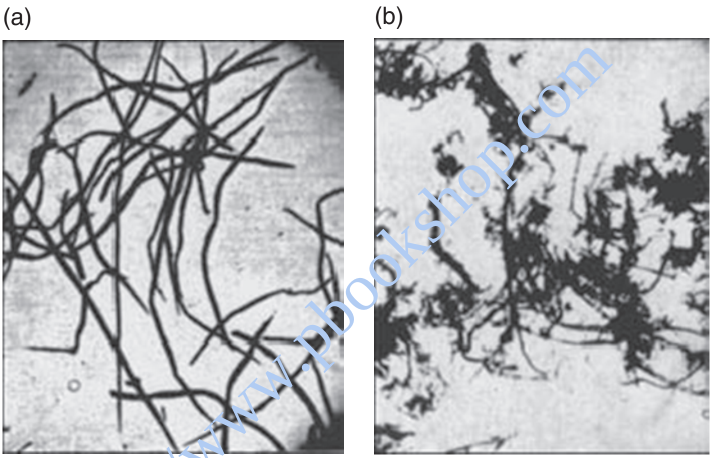

Figure 1.5 Fibres on (a) before beating and (b) after being well beaten for greaseproof paper manufacture. (Courtesy of PITA.)

1.2.8 Manufacture on the paper or paperboard machine

The basic principles of papermaking today are the same as they have always been:

- prepare a dilute suspension of fibres in water
- form a sheet consisting of an overlapping network of fibres
- remove most of the water progressively by drainage, pressure and evaporation (drying).

Traditionally, forming was achieved manually by dipping a finely woven flat wire mesh set in a wooden frame, called a mould, into a vat of fibres suspended in water and allowing excess suspension to flow over a separate wooden frame, or deckle, fitted around the edge of the mould. Water was drained through the wire mesh. The deckle was removed when the layer of fibres had consolidated. This resulted in a sheet where the fibres were randomly and evenly distributed (Fig. 1.6).

The mould was then inverted and the sheet transferred (couched) to a wetted felt blanket (Fig. 1.7). The wet sheet was covered by another felt. This process was repeated several

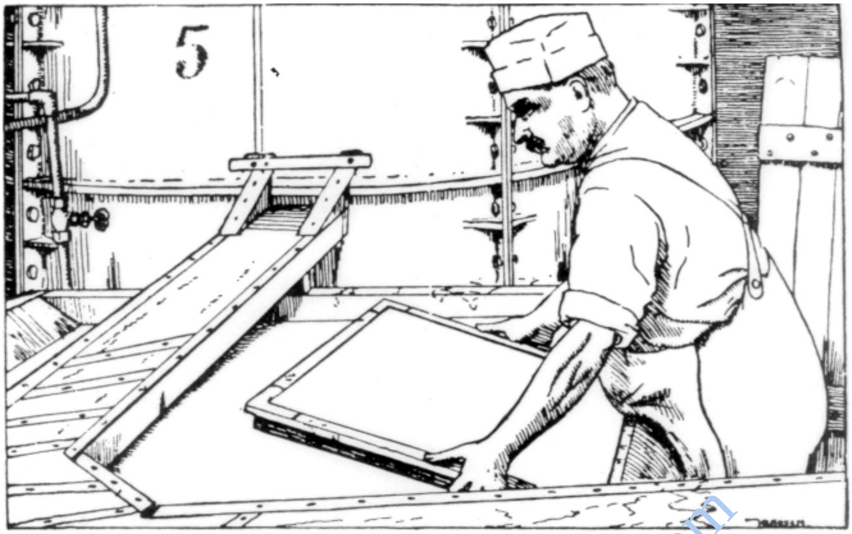

Figure 1.6 Vatman hand-forming paper sheet using mould. (Courtesy of PITA.)

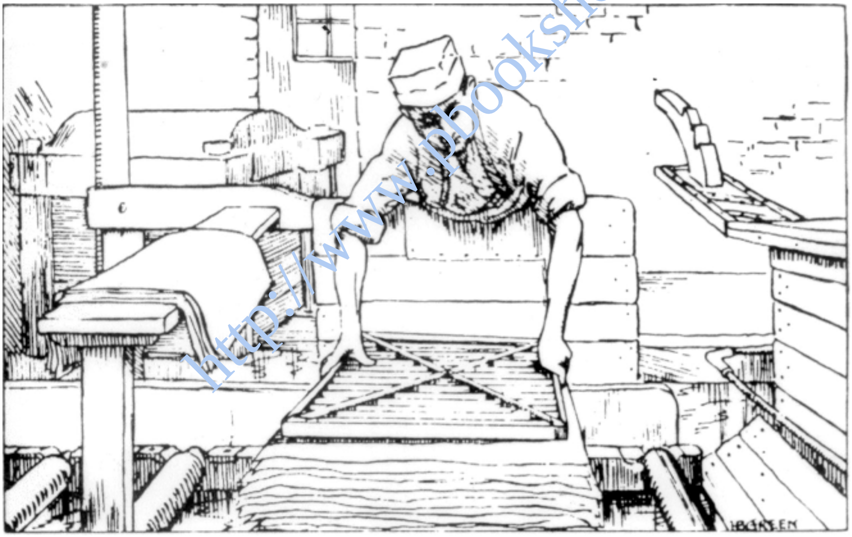

Figure 1.7 Coucher removing wet sheet from mould. (Courtesy of PITA.)

times to form a pile of alternate layers of wet sheets and felts, known as a post, which was then subjected to pressure in a mechanical or hydraulic press to squeeze water from the sheets. After this process, the sheets were strong enough to be handled and separated from the felts.

Further pressing without felts removed more water, after which the sheets were dried in air. Sheets intended for printing would then be tub-sized by immersion in a solution of gelatine, pressed and re-dried in air (Fig. 1.8).

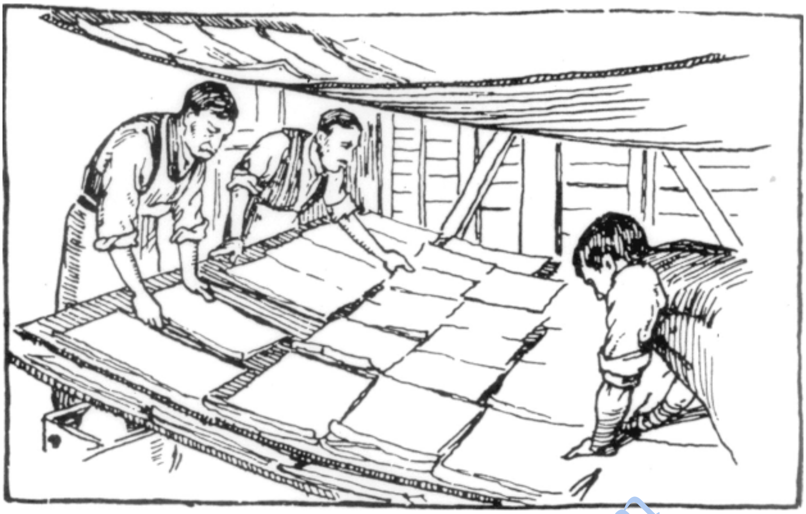

Figure 1.8 Loft-drying handmade paper. (Courtesy of PITA.)

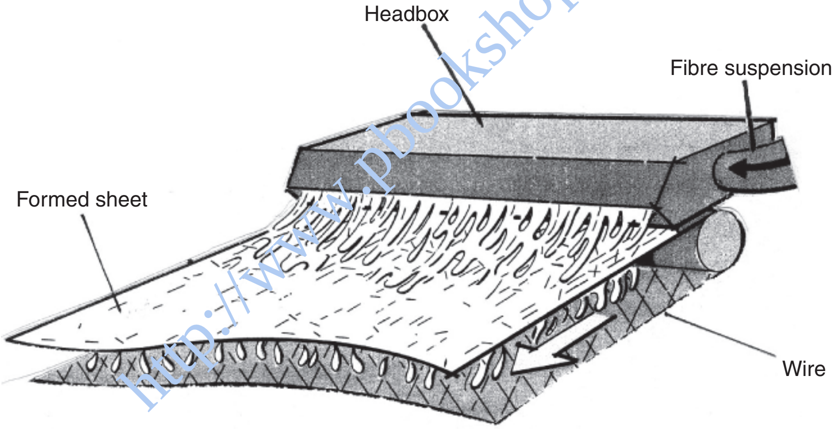

Figure 1.9 Simplified diagram of the forming process (Fourdrinier). (Courtesy of Iggesund Paperboard.)

The Industrial Revolution facilitated progress from laborious manual operations, one sheet at a time, to today's continuous high-speed production, using computerised process control.

Whilst the principles of sheet forming, pressing and drying are common to all paper and paperboard, the way in which it is carried out depends on the specific requirements and the most cost-effective method available.

Since the early 1800s, pulp has been mechanically applied to a wire mesh on a paper or paperboard machine. Mechanical forming (Fig. 1.9) induces a degree of directionality in the way the fibres are arranged in the sheet. As the fibres are relatively long in relation to their width, they tend to line up, as the sheet is formed, in the direction of motion along the machine. This direction is known as the machine direction (MD), and whilst fibres line up

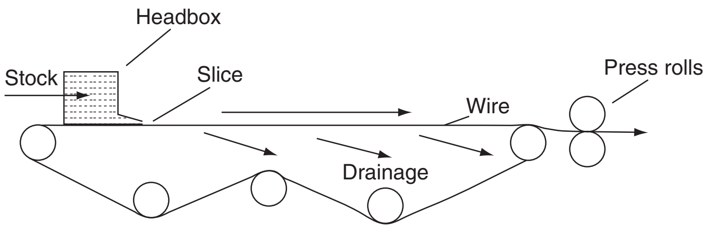

Figure 1.10 Sheet forming on moving wire – Fourdrinier process.

in all directions the least number of fibres will line up in the direction at right angles to the MD, which is known as the cross direction (CD).

The techniques used prior to and during forming are very important for the performance of the product. Strength properties and other features show variations characterised by these two directions of property measurement. The significance of this feature for the printing, conversion and use of paper and paperboard packaging varies depending on the application, and users should be aware of the implications in specific situations. Examples are discussed in the chapters on the various types of packaging.

It is important that the weight per unit area and the distribution of fibre orientation are functionally adequate and consistent, both within makings and from making to making, for the intended use.

There are two main methods of forming. Wire forming – where the pulp suspension in water, with a consistency of around 1% fibre and 99% water, flows from a headbox out of a narrow horizontal slot, known as the slice, onto a moving wire – was originated by Nicolas Robert in France in 1798. The initial method required further development by others, particularly Bryan Donkin, before the first continuous paper machine, financed by the Fourdrinier brothers, was installed at Frogmore Mill, Herts, England, in 1803. The name 'Fourdrinier' has been adopted to describe this method of forming (Fig. 1.10).

The wire, which is usually a plastic mesh today, may have a transverse 'shake' from side to side to produce a more random orientation of fibre. Water is drained from the underside of the wire using several techniques, including vacuum. The wet web is removed from the wire when it can support its own weight, at which point its solids content will be around 20%. This section of the machine is called the wet end, and the wire, which is a continuous band, carries on around to receive more pulp suspension.

An alternative method of mechanical forming using a wire-covered cylinder was also being developed at the same time. The patent which led to a successful process was taken out by John Dickinson in 1809 and he was making paper in quantity at Apsley and Nash mills also in Herts, England, by 1812. In this process, the wire-covered cylinder revolves in a vat of pulp which forms a sheet on the surface of the cylinder as a result of the maintenance of a differential pressure between the outside and inside of the cylinder. Figure 1.11 shows a 'uniflow' vat where the pulp suspension flows through the vat in the same direction as the wire mould is rotating. This arrangement results in good sheet formation, whereas if the pulp suspension flows in the opposite direction, in what is known as a contraflow vat, higher weights of pulp are formed on the mould.

Multi-web, or *multi-ply*, sheet forming can be achieved by using several wires or several vats. A modification of the wire-forming method is the Inverform process where a second and subsequent headboxes add additional layers of pulp. As each layer is added, a top wire contacts the additional layer and drains water upwards as a result of the

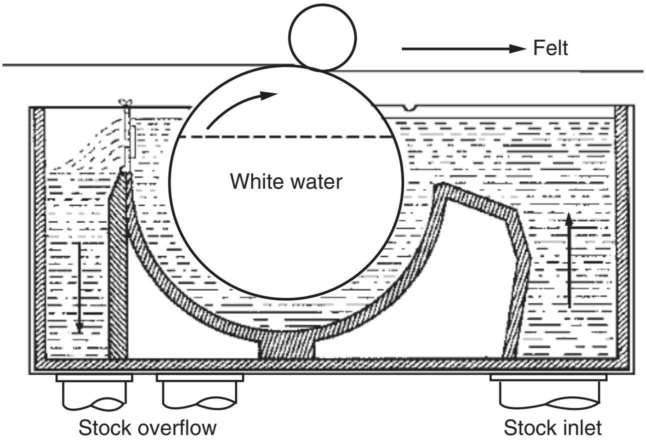

Figure 1.11 Uniflow vat cylinder mould forming. (Courtesy of PITA.)

mechanical design which is assisted with vacuum. This resulted in a significant increase in productivity without loss of quality.

Multilayering enables the manufacturer to make heavier weight per unit area products and use different pulps in the various layers to achieve specific functional needs cost-effectively. Multilayering in the case of thicker grades of paperboard also facilitates weight control and good creasing properties.

Following the forming process, the next water removal operation occurs in the press section. More water is removed by pressing the sheet, sandwiched between supporting blankets or felts, often accompanied by vacuum-induced suction. This increases the solids content to around 45–55%. Thereafter the sheet is dried in contact with steam-heated steel cylinders, producing a typical final solids content of 92–95%.

Some products are made on machines with a large diameter machine glazing (MG) or 'Yankee' cylinder. The web is applied to the cylinder whilst the moisture content is still high enough for it to adhere to the polished hot surface. This process not only dries the web but also promotes a polished or glazed smooth surface. Papers produced in this way have the prefix 'MG'. An important aspect of this for some products is that a smooth surface is achieved without loss of thickness – a feature which preserves stiffness, the importance of which will be discussed later.

Surface sizing can be applied to one or both surfaces during drying. Starch may be used to improve strength and prevent any tendency for fibre shedding during printing. Grease-resistant additives may also be applied in this way. A wax size may be applied as an emulsion in water, and with the heat from the drying cylinders the wax impregnates the paper or paperboard. However, the majority of wax treatments are applied as secondary conversion processes, i.e. off-machine. Sometimes, pigment is mixed with the starch added at this point to produce a lightweight coating to improve printability.

The final process before the web is wound into a reel involves calendering, where the dry paper is passed between smooth cylinders; this both enhances smoothness or finish and controls thickness and thickness profile. Calendering can be applied in several ways depending on the product and the surface finish required. Cylinders may be hard or soft, heated or chilled, and in some cases water is applied to the surface of the material during the process. At its simplest, calendering comprises two steel rolls though more could be used – this is the

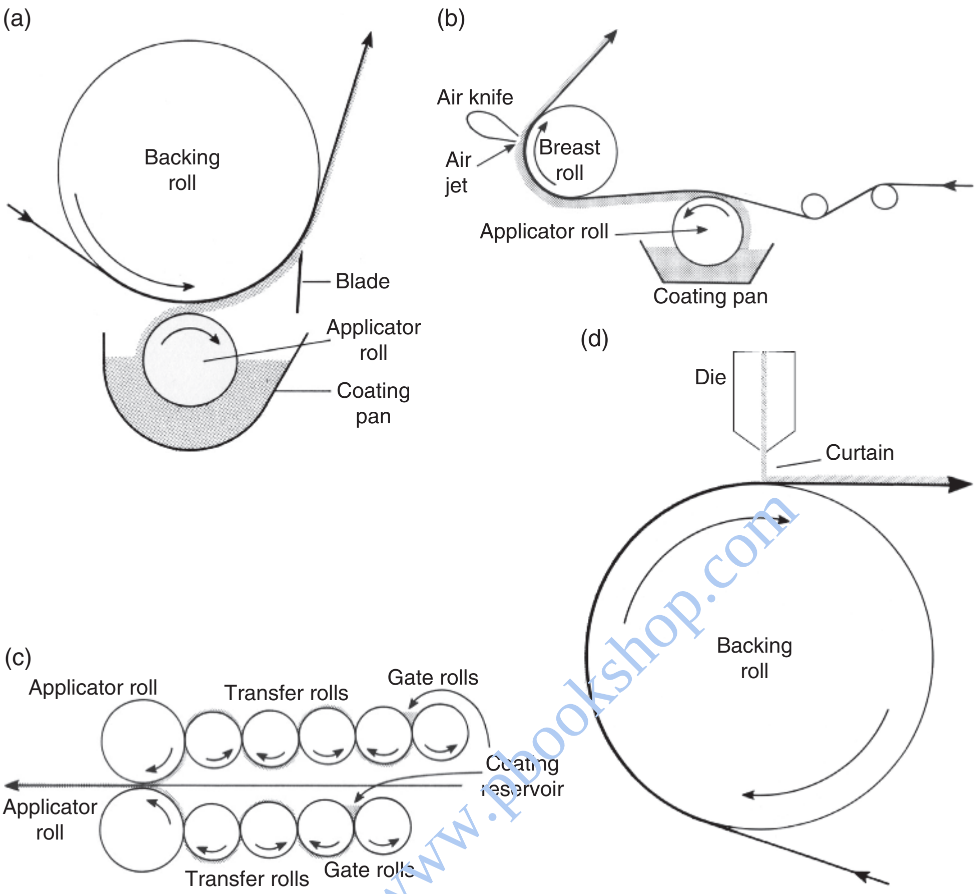

Figure 1.12 (a) Blade coating, (b) air knife coating, (c) roll coating and (d) curtain coating. (Courtesy of PITA.)

oldest and most basic method, which can result in significant reduction in thickness. Paperboard in general requires light calendering to control thickness without compressing the material excessively, which would reduce stiffness, as will be discussed later; this is best achieved by using soft calender bowls, rather than steel rolls. With soft bowls, high smoothness can be achieved without crushing the material, and reduction of caliper is minimised, so stiffness is maintained.

There are paper machines with up to seven calender rolls where steel and composite rolls are used alternatively to provide smoother and glossier finishes. An off-machine ‘supercalender’ (SC) produces a much smoother and glossier finish. In the case of glassine, as many as 14 rolls are used in SC.

White pigmented mineral-based coatings are applied, to one or both sides of the sheet, and smoothed and dried, to improve appearance in respect of colour, smoothness, printing and varnishing. One, two or three coating layers may be applied, depending on the needs of the product. In general, if a single layer is applied, it may be done in-line, after surface sizing and before calendering. Subsequent layers are more often applied off-line, in a separate process.

The method of coating (Fig. 1.12) has been adopted to describe the types of coating, such as blade, air knife, roll, bar or curtain. For packaging applications, blade has traditionally been

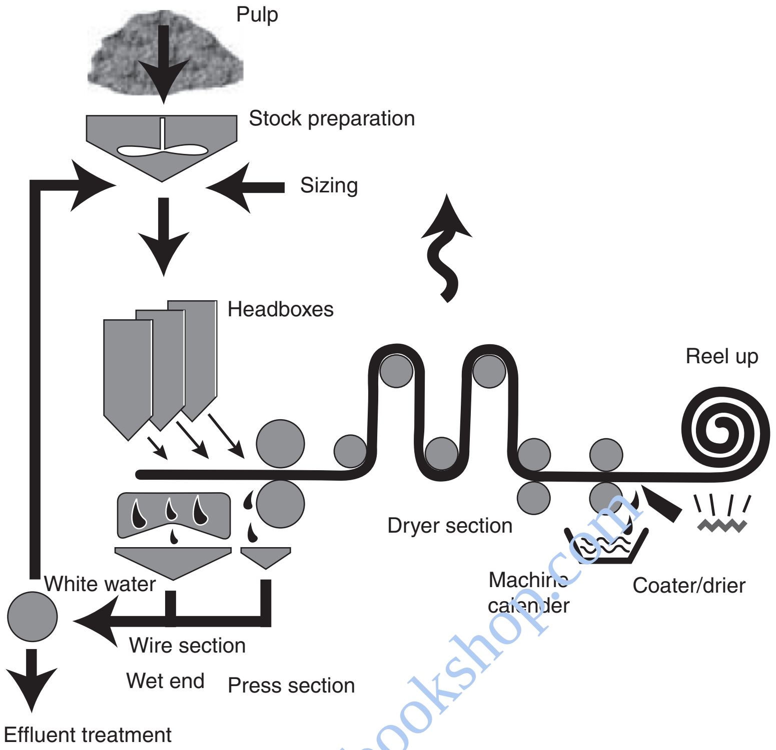

Figure 1.13 Principal features of paper/paperboard manufacture by wire forming – the number of headboxes will vary depending on the product and the machine design. (Courtesy of Pro Carton.)

the most popular technique, although curtain is just starting to gain in popularity. The advantage of curtain coating over the other methods is that there is no physical contact between the coater and paper web; this reduces the occurrence of web breaks, so increasing productivity.

The coating process described produces a surface with a matt finish. A more light-reflective gloss finish can be achieved by brushing, friction glazing or calendering.

A specific type of mineral pigment coating is known as cast coating, which is applied off-machine as a separate process. This is a reel-to-reel process in which the coating mix is applied to the paper or paperboard surface, smoothed, and whilst still wet is cast against the surface of a highly polished heated cylinder, similar to a Yankee or MG cylinder. When dry, the coated surface peels away from the cylinder leaving a coating on the paper or paperboard with a very smooth and extremely high gloss finish.

Paper and paperboard machines vary in width from around 1 m to as much as 10 m. The size is geared to output and output is geared to market size. The output-limiting factors for a given width are the amount of pulp used per unit area and the linear speed – both of which relate to the amount of water that has to be removed by a combination of drainage, vacuum, pressing and drying. Principal features of paper/paperboard manufacture by wire forming are shown in Fig. 1.13.

1.2.9 Finishing

This is the name given to the processes which are carried out after the paper and paperboard have left the papermaking machine. There are a number of options depending on customer requirements. Large reels ex-machine are slit to narrower widths and smaller diameters; subsequently, such reels may be slit, sheeted, counted, palletised, wrapped and labelled. The product is normally wrapped in moisture-resistant material such as PE, film and stretch or shrink wrap.

Papers and paperboards produced in the way described may be given secondary treatments by way of coating, lamination and impregnation with other materials to achieve specific functional properties. These are known as 'conversion' processes. They are performed after the paper and paperboard have left the mill either by specialist converters, such as laminators or plastic-extrusion coaters, or they may be integrated within the plants making packaging materials and containers. These processes are discussed in the packaging-specific chapters of this book.

We have now identified the nature of paper and paperboard, the raw materials and the processing which can be undertaken to make a wide range of substrates. We now need to review the various paper and paperboard products which are used to manufacture packaging materials and containers.

1.3 Packaging papers and paperboards

1.3.1 Introduction

A wide range of papers and paperboards are commercially available to meet market needs based on the choice of fibre (bleached or unbleached, chemically or mechanically separated, virgin or recovered fibre), the treatment and additives used at the stock-preparation stage.

We have noted that paper- and paperboard-based products can be made in a wide range of grammages and thicknesses. The surface finish (appearance) can be varied mechanically. Additives introduced at the stock-preparation stage provide special properties. Coatings applied to either one or both surfaces, smoothed and dried, offer a variety of appearance and performance features which are enhanced by subsequent printing and conversion, thereby resulting in various types of packaging material. To illustrate these features of paper and paperboard, some typical product examples are described later.

1.3.2 Tissues

These are lightweight papers with grammages from 12 to 30 g m^{-2}. The lightest tissues for tea and coffee bags which require a strong porous sheet are based on long fibres such as those derived from Manila hemp. To maintain strength during immersion in boiling water, wet strength additives are used. The Constanta-type bag with the lowest grammage is folded and stapled. Heat-sealed tea and coffee bags require the inclusion of a heat-sealing fibre, such as PP. Single-portion tea bags have grammages in the range 12–17 g m^{-2}, but larger bags would require higher grammages.

Neutral pH tissue grades with low chloride and sulphate residues are used as wrapping materials for archival purposes; such specialist tissue may also be laminated to aluminium foil and used to wrap silverware, jewellery, clothing, etc. (Packaging tissues should not be confused with absorbent tissues used for hygienic purposes, which are made on a different type of paper machine using different types of pulp.)

1.3.3 Greaseproof

The hydration (refining) of fibres at the stock-preparation stage, already described, is taken much further than normal. Hydration can also be carried out as a batch process in a beater. The fibres are treated (hydrated) so that they become almost gelatinous. Grammage range is 30–70 g m^{-2}.

1.3.4 Glassine

This is a SC greaseproof paper. The calendering produces a very dense sheet with a high (smooth and glossy) finish. It is non-porous, greaseproof and can be laminated to paperboard. It may be plasticised with glycerine. It may be embossed, PE coated, aluminium foil laminated, metallised or release-treated with silicone to facilitate product release. It is produced in plain and coloured versions, for example chocolate brown. Grammage range is 30–80 g m^{-2}.

1.3.5 Vegetable parchment

Bleached chemical pulp is made into paper conventionally and then passed through a bath of sulphuric acid, which produces partial hydrolysis of the cellulose surface of the fibres. Some of the surface cellulose is gelatinised and redeposited between the surface fibres forming an impervious layer closing the pores in the paper structure. The process is stopped by chemical neutralisation and the web is thoroughly washed in water. This paper has high grease resistance and wet strength. It can be used in the deep freeze (i.e. −20°C storage environment) and in both conventional and microwave ovens. It can be silicone treated for product release. Grammage range is 30–230 g m^{-2}.

1.3.6 Label paper

These may be coated, MG (machine glazed) or MF (machine finished – calendered) kraft papers (100% sulphate chemical pulp) in the grammage range 70–90 g m^{-2}. The paper may be coated on-machine or cast coated for the highest gloss in an off-machine or secondary process.

The term ‘finish’ in the paper industry refers to the surface appearance. This may be:

- machine finish (MF) – smooth but not glazed
- water finish (WF) – where one or both sides are dampened and calendered to be smoother and glossier than MF
- machine glazed (MG) – with high gloss on one side only
- supercalendered (SC) – which is dampened and polished off-machine to produce high gloss on both sides.

Depending upon the environment in which the label is to be used, various functional chemicals may need to be added, for example for labelling packages containing fatty products, grease-resistant chemicals, such as fluorocarbons, may be included.

1.3.7 Bag papers

‘Imitation kraft’ is a term on which there is no universally agreed definition; it can be either a blend of kraft virgin fibre with recycled fibre or 100% recycled. It is usually dyed brown.

It has many uses for wrapping and for bags where it may have an MG and a ribbed finish. Thinner grades may be used for lamination with aluminium foil and PE for use on form, fill, seal machines. For sugar or flour bags, coated or uncoated bleached kraft in the range 90–100 g m^{-2} is used.

1.3.8 Sack kraft

Usually this is unbleached kraft (90–100% sulphate chemical) pulp, though there is some use of bleached kraft. The grammage range is 70–100 g m^{-2}.

Paper used in wet conditions needs to retain considerable strength, at least 30%, when saturated with water. To achieve this, resins such as UF and MF are added to the stock. These chemicals cross-link during drying and are deposited on the surface of the cellulose fibres making them more resistant to water absorption.

Microcreping, as achieved for example by the Clupak process, builds an almost invisible crimp into paper during drying, enabling it to stretch up to 7% in the MD compared to a more normal 2%. When used in paper sacks, this feature improves the ability of the paper to withstand dynamic stresses, such as occur when sacks are dropped.

1.3.9 Impregnated papers

Papers are made for subsequent impregnation off-machine. Such treatment can, for example, be with wax, vapour-phase inhibitor for metal packaging and mould inhibitors for soap wrapping. (Mills have ceased to impregnate these products on-machine for technical and commercial reasons.)

1.3.10 Laminating papers

Coated and uncoated papers based on both kraft (sulphate) and sulphite pulps can be laminated to aluminium foil and extrusion coated with PE. The heavier weights can be PE laminated to plastic films and wax or adhesive laminated to unlined chipboard. The grammage range is 40–80 g m^{-2}.

1.3.11 Solid bleached board (SBB)

This board (Fig. 1.14) is made exclusively from bleached chemical pulp. It usually has a mineral pigment-coated top surface, and some grades are also coated on the back. The term ‘solid bleached sulphate’ (SBS), derived from the method of pulp production, is sometimes used to describe this product.

This paperboard has excellent surface and printing characteristics. It gives wide scope for innovative structural designs and can be embossed, cut, creased, folded and glued with ease. This is a pure cellulose primary (virgin) paperboard with consistent purity for food product safety, making it the best choice for the packaging of aroma and flavour-sensitive products. Examples of use include chocolate packaging, frozen, chilled and reheatable products, tea, coffee, liquid packaging and non-foods such as cigarettes, cosmetics and pharmaceuticals.

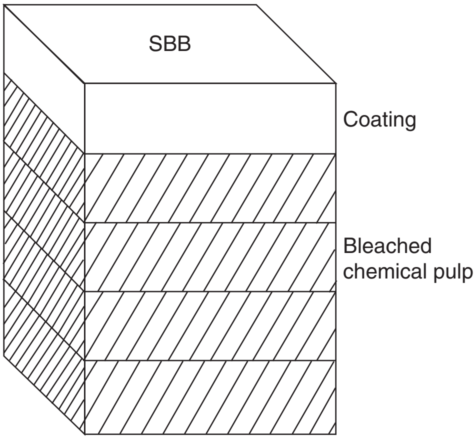

Figure 1.14 Solid bleached board. (Courtesy of Iggesund Paperboard.)

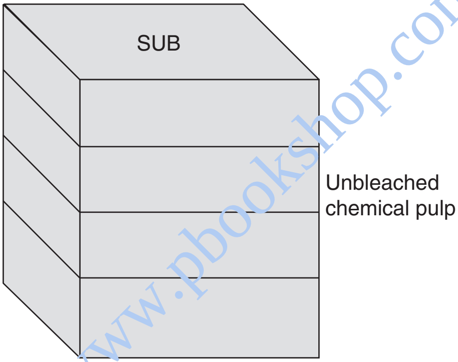

Figure 1.15 Solid unbleached board (SUB). (Courtesy of Iggesund Paperboard.)

1.3.12 Solid unbleached board (SUB)

This board (Fig. 1.15) is made exclusively from unbleached chemical pulp. The base board is brown in colour. This product is also known as ‘solid unbleached sulphate’ (SUS). To achieve a white surface, it can be coated with a white mineral pigment coating, sometimes in combination with a layer of bleached white fibres under the coating.

SUB is used where there is a high strength requirement in terms of puncture and tear resistance and/or good wet strength is required such as for bottle or can multipacks and as a base for liquid packaging.

1.3.13 Folding boxboard (FBB)

This board (Fig. 1.16) comprises middle layers of mechanical pulp sandwiched between layers of bleached chemical pulp. The top layer of bleached chemical pulp is usually coated with a white mineral pigment coating. The back is cream (manila) in colour. This is because the back layer of bleached chemical pulp is translucent, allowing the colour of the middle layers to show through. However, if the mechanical pulp in the middle layers is given a mild chemical treatment, it becomes lighter in colour and this makes the reverse side colour lighter in shade.

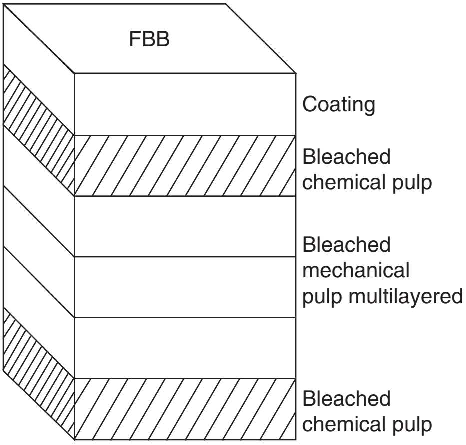

Figure 1.16 Folding boxboard. (Courtesy of Iggesund Paperboard.)

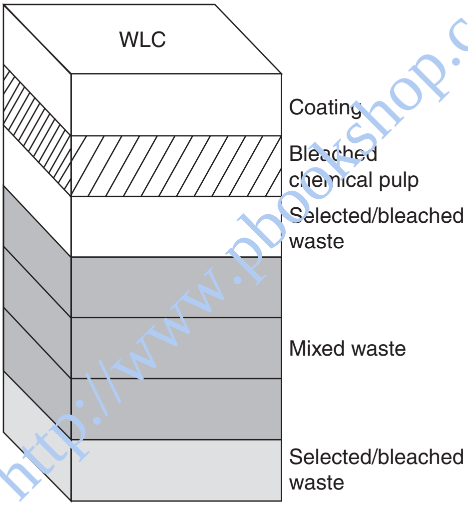

Figure 1.17 White-lined chipboard. (Courtesy of Iggesund Paperboard.)

The back layer may, however, be thicker or coated with a white mineral pigment coating, thus becoming a white back-folding boxboard. The combination of inner layers of mechanical pulp and outer layers of bleached chemical pulp creates a paperboard with high stiffness.

Fully coated grades have a smooth surface and excellent printing characteristics. This paperboard is a primary (virgin fibre) product with consistent purity for food product safety and suitable for the packing of aroma- and flavour-sensitive products. It is used for packing confectionery, frozen, chilled and dry foods, healthcare products, cigarettes, cosmetics, toys, games and photographic products.

1.3.14 White-lined chipboard (WLC)

WLC (Fig. 1.17) comprises middle plies of recycled pulp recovered from mixed papers or carton waste. The middle layers are grey in colour. The top layer, or liner, of bleached chemical pulp is usually white mineral pigment coated. The second layer, or under liner, may also comprise bleached chemical pulp or mechanical pulp. This product is also known as newsboard or chipboard, though the latter name is more likely to be associated with unlined grades, i.e. no white, or other colour, liner.

The reverse side outer layer usually comprises specially selected recycled pulp and is grey in colour. The external appearance may be white due to the use of bleached chemical pulp and, possibly, a white mineral pigment coating (white PE has also been used).

There are additional grades of unlined chipboard and grades with specially coloured (dyed) liner plies. (WLC with a blue inner liner was used for the packing of cube sugar.)

The overall content of WLC varies from about 80 to 100% recovered fibre depending on the choice of fibre used in the various layers. WLC is widely used for dry foods, frozen and chilled foods, toys, games, household products and DIY.

1.4 Packaging requirements

Packaging protects and identifies the product for customers/consumers. When we think about packaging requirements, we may initially think of the needs of the customer who is the purchaser of a branded product in a supermarket (supplier). However, the purchaser is not always the consumer or user of the product, and closer investigation also brings the realisation that there is a wide range of important needs which must be met at several supplier/customer interfaces in a chain, which links the:

- supply of raw materials, for example pulp, coatings, etc.
- manufacture of packaging material, for example papermaker
- manufacture of the pack or package components, for example printer, laminator, converter
- packing/filling of the product, for example food manufacturer
- storage and distribution, for example regional depot, wholesaler or ‘cash and carry’
- point of sale, provision or dispensing to customer, for example retailer, pharmacy, etc.

At every stage, there are functional requirements which must be met. These requirements must be identified and built into the specification of the pack and the materials used for its construction. The specification for a primary consumer-use pack must also be compatible with the specification of the secondary distribution pack and the tertiary palletisation or other form of unit load.

Packaging requirements can be identified with respect to:

- *protection, preservation and containment* of the product to meet the needs of the packaging operation and the proposed distribution and use within the required shelf life
- *efficient production* of the packaging material, the pack in printing and converting, in packing, handling, distribution and storage, taking account of all associated hazards
- *promotion* requirements of visual impact, display and information throughout the packaging, sale and use of the product.

Checklists can be used to carry out these tasks logically to ensure that all important potential needs are examined (see Appendix, “Checklist for a packaging development brief”).

Whilst the overall needs are defined by marketing and those responsible for the product itself, these needs have to be interpreted by packaging technologists and packaging buyers in both end-user and retailer and by production, purchasing and technical departments in printers, converters and manufacturers of the packaging.

The next step is to match these requirements with the knowledge about the ability of the proposed material, and the package which can be manufactured from that material, in order to achieve the requirements effectively. This implies making *choices*. A technologist, using this term in a general sense, assists this process using his/her knowledge about materials and the packages which can be made from these materials, methods of packing and the general logistical environment within which the business concerned operates. Ultimately, packaging must meet the needs of society in a sustainable way by:

- minimising product waste
- improving the quality of life
- protecting the environment
- managing packaging waste through recovery and recycling.

All these requirements have technical implications, and in order to meet the requirements at every stage in the manufacture and use of the packaging, paper and paperboard must be carefully selected on the basis of their properties and other relevant features.

We will now examine those physical properties and other features of paper and paperboard with technical implications which relate to their performance in printing, conversion and use.

1.5 Technical requirements of paper and paperboard for packaging

1.5.1 Requirements of appearance and performance

The properties of paper and paperboard correlating with the needs of printing, its conversion into packages and their use in packing, distribution, storage, product protection and consumer use can be identified and measured.

All paper and paperboard properties depend on the ingredients used, for example type and amount of fibre and other materials, together with the manufacturing processes. These properties of the paper and paperboard are related to the visual appearance and technical performance of packaging incorporating such materials:

- appearance that relates to colour, visual impression and the needs of any processes, such as printing, which have a major impact on the appearance of the packaging
- performance that relates to strength, product/consumer protection and the efficiency of all the production operations involved in making and using the packaging.

1.5.2 Appearance properties

1.5.2.1 *Colour*

Colour is a perceived sensation of the human eye and brain, which depends on the viewing light source and the ability of the illuminated surface to absorb, reflect and scatter that illumination. The lighting conditions under which the colour of paper and paperboard is viewed have been standardised so that different observers can make judgements about colour. Colour measurement has been standardised so that specifications can be defined.

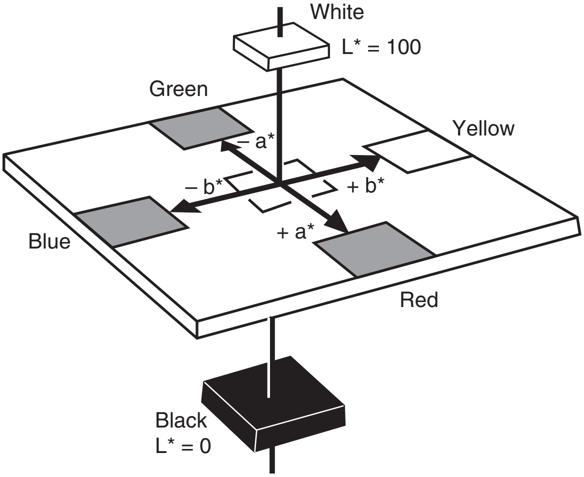

Figure 1.18 CIELAB colour coordinates. (Courtesy of Iggesund Paperboard.)

The colour of paper and paperboard is usually white or brown depending on whether the fibre is bleached or unbleached (brown). The outer surface, and sometimes the reverse side, may be pigment coated. Coating is usually white though other colours are possible. Other colours are also possible in uncoated products through the use of dyes added at the stock-preparation stage. Recycled mixed fibres which are not de-inked have a grey colour commonly seen on the reverse side of WLC.

Colour is assessed by eye under specified conditions of lighting. It is measured using reflected light from a standard light source in a reflectance spectrophotometer and calculating the colour values (Commission International de l'Éclairage (CIE) coordinates).

Natural daylight, or a simulated equivalent, is used as the source for viewing. CIE is recognised as the scientific authority with respect to colour in the paper, printing and packaging industries. The CIE colour coordinates (Fig. 1.18), L*, a* and b*, are used to express lightness and colour using a standard D65 light source which simulates natural daylight.

Positive figures for a* indicate redness, negative figures greenness; positive b* indicates yellowness, negative figures blueness; and L* is the percentage for luminance (intensity of light) on a scale where black is zero and pure white 100%. (A top of the range specification for a white paperboard-coated surface would be around a* +2, b* –5 and L* 97.)

CIE whiteness is another measurement that is often quoted for paper and paperboard. CIE whiteness values are calculated from the same reflectance data used to produce CIE colour coordinates. However, instead of producing three values, the fundamental reflectance data are manipulated to produce just two numbers: one for whiteness and the other for tint. The former ranges from around 50, which has a noticeably yellow shade, to around 180 – a value that is only possible by use of OBA or FWA. Tint refers to the relative deviation from true white towards green or red; for a paper to be classed as white, the tint value must lie between –3 and +3. Whiteness is the preferred measurement over L* or brightness for 'white' papers because it highlights reflectance data from the wavelength region where the human eye is most sensitive and it expands the scale compared to the other two similar variables, making differentiation of substrates easier.

There are many different examples of whiteness, or hue, found in packaging papers and paperboards. It is relatively easy to develop a specific whiteness/hue when using a mineral-based coating, and the perceived colour can be modified with additional components such as dyes and OBA or FWA. However, the base sheet colour, which depends on its composition, influences the colour of a pigment-coated surface. In packaging today, a whiteness with a bluish hue is preferred for primary retail packaging as this is felt to give the best appearance for food products, suggesting freshness, hygiene and high quality under shop (retail) lighting. Meanwhile, many secondary packaging grades of paper and paperboard, such as cardboard, are brown as they do not incorporate bleached fibre.

Brightness is often mentioned in the same context as colour and whiteness, but it is *not* comparable. Brightness is the percentage of blue light of nominal wavelength 457 nm reflected from the surface. The human eye perceives a range of wavelengths from under 400 to over 700 nm but has its greatest sensitivity in the range 470–650 nm, so the wavelength chosen for brightness measurement is below the optimum perceptual range for humans. This means values for brightness do not correlate well with human perception. Normally brightness is only measured on pulp. As it measures reflectance at a narrow band of wavelengths of blue light, it is of little value to a printer or end-user of packaging.

1.5.2.2 *Surface smoothness*

Surface smoothness is an important aesthetic feature and is also functionally important with respect to printing and varnishing. With some print processes, a rough paper would not faithfully reproduce the printing image as a result of 'dot skip', where ink has not been transferred from the plate, for example in the gravure printing process, to the surface being printed.

Surface smoothness is usually measured as surface roughness by air leak methods (Fig. 1.19) – the rougher the surface, the greater the rate of air leakage, at a specified air pressure, from under a cylindrical knife edge placed on the surface. Hence, the rougher the surface, the higher the value. As papers and paperboards are compressible, the pressure exerted by the knife edge is specified. By measuring roughness at two specified knife-edge pressures, an indication of compressibility is also achieved. (Compressibility is also important in printing.) The most common roughness measurements are based on the Parker Print Surf (PPS), Bendtsen and Sheffield instruments.

Occasionally, mainly for historical reasons, some markets measure surface smoothness using alternative air leak instruments, such as the Bekk smoothness tester. In this apparatus, a sample is placed against an optically smooth glass plate with a hole in the centre, and a chamber under the plate is evacuated to produce an under-pressure using a vacuum pump. When the pump is stopped, air bleeds between the paper surface and glass plate, enters the chamber and reduces the under-pressure. The time taken for a known change in pressure, corresponding to the passage of a known volume of air between paper and plate, is measured; high values indicate smoother paper surfaces. The clamping pressure and degree of paper or paperboard compression is different from that used in roughness measurement, and experience shows Bekk smoothness is not as reliable at predicting surface quality as roughness measurement techniques.

1.5.2.3 *Surface structure*

Surface structure is assessed visually by observing the surface under low-angle illumination (Fig. 1.20) which highlights any irregularities in the surface. The appearance varies depending on the direction, i.e. MD or CD, of observation and illumination. The surface

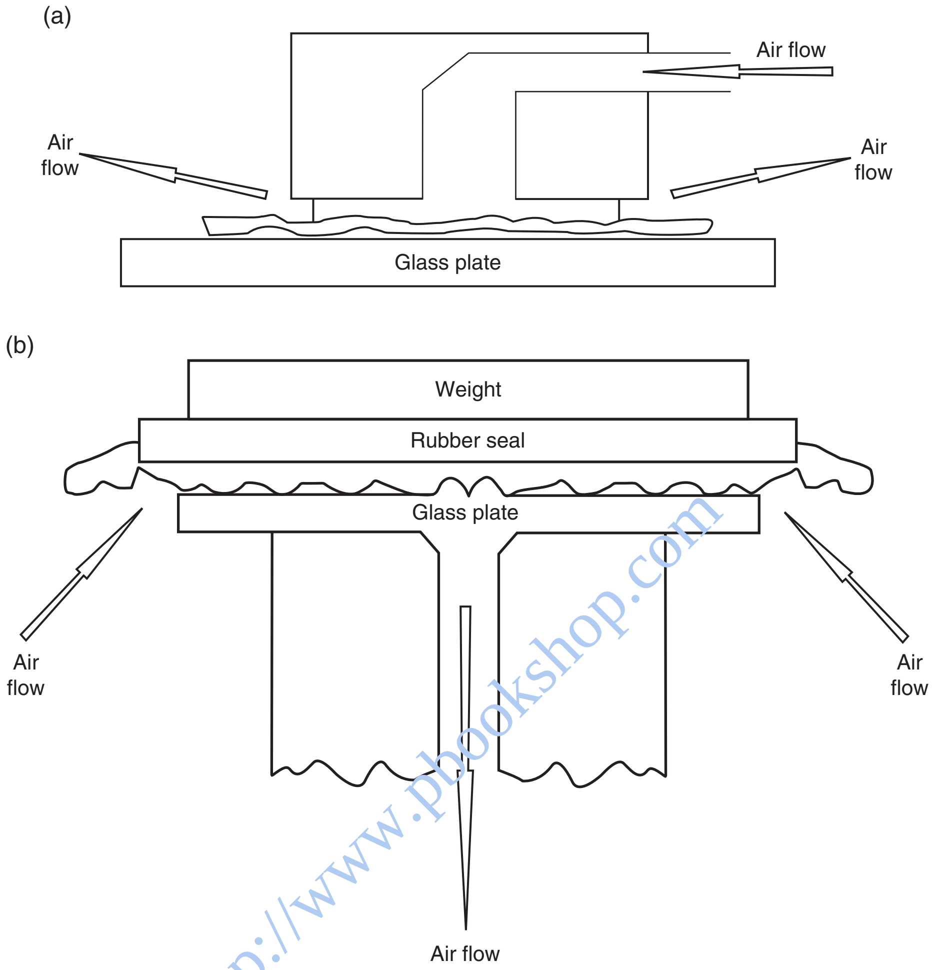

Figure 1.19 (a) Surface roughness, measuring principle of the Bendtsen, Sheffield and Parker Print Surf roughness testers and (b) surface roughness, measuring principle of the Bekk smoothness tester.

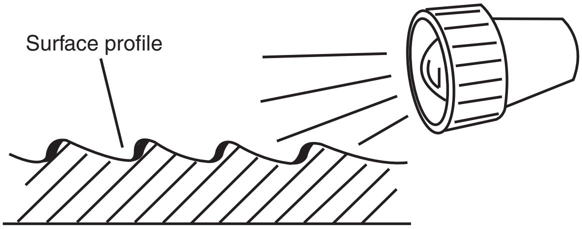

Figure 1.20 Low-angle illumination to examine surface irregularities. (Courtesy of Iggesund Paperboard.)

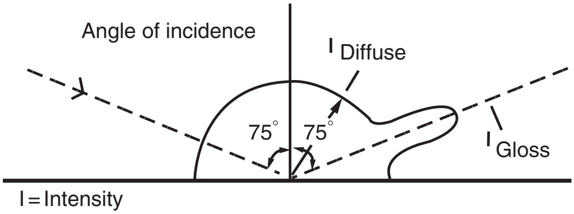

Figure 1.21 Principle of gloss measurement for paper and paperboard. (Courtesy of Iggesund Paperboard.)

structure is usually not fully apparent until the surface is varnished or laminated with either a transparent film or aluminium foil.

1.5.2.4 *Gloss*

Gloss is defined as the percentage of light reflected from the surface at the same angle as the angle of incidence. For better discrimination, the gloss of paper and paperboard is measured at an angle of 75° (Fig. 1.21), and printed and varnished surfaces are measured at 60°. Glossy surfaces are usually achieved with mineral pigment-coated surfaces which have been calendered, brush burnished, friction glazed or cast coated.

With uncoated papers, gloss is achieved by drying the paper or paperboard on an MG cylinder with a polished surface, as, for example, with MG bleached or unbleached kraft papers. The high gloss of a glassine is developed on an SC, where it is passed through several nips, i.e. the gaps between alternate hard metal and soft rolls made from compressed fibrous material.

1.5.2.5 *Opacity*

Opacity relates to the capacity of a sheet to obscure print on an underlying sheet or on the reverse of the sheet itself. This is required in a packaging context where paper is used as an overwrap on top of a printed surface. Opacity is measured by comparing light reflectance, using a spectrophotometer, from the surface of a single sheet over a black background with the reflectance from a pile of 100 sheets of the same grade.

1.5.2.6 *Printability and varnishability*

Packaging is usually printed to provide information, illustrations and to enhance visual display. Print may be varnished or sealed to give improved gloss and to protect print. The colour of the surface and the print design, text, solid colour and half-tone illustrations, and whether the print is varnished or sealed, all have a major impact on the appearance.

There is a wide range of print design in packaging as evidenced by the needs of, for example, multiwall paper sacks for cement, sugar bags, labels for beer bottles, cartons for breakfast cereals and the packaging used for brand leaders in chocolate assortments or expensive cosmetics. These examples will also be different compared with the printing on transit or shipping cases, used in distribution, or the labels on hazardous chemicals packaging.

Several printing processes are used commercially today. They are discussed in the package-specific chapters which follow. These processes include offset lithography, flexography, letterpress, gravure, silkscreen and digital printing. They vary in several important characteristics, chiefly in relation to the ink and varnish formulations, the techniques by which they are applied to the paper or paperboard substrate and the processes by which they dry and become permanent and durable.

Despite the variability, there are common features relating to printability which apply to all papers and paperboards. They comprise surface smoothness, surface structure, gloss level, opacity, surface strength, ink and varnish absorption, drying, rub resistance together with edge and surface cleanliness. In specific cases, surface pH and surface tension or wettability are also relevant.

Print colour can be measured using a spectrophotometer or with a densitometer. It can also be compared visually, under standardised lighting, with pre-set colour standards, to ensure that colours remain within acceptable light, standard and dark limits.

1.5.2.7 *Surface strength*

Adequate surface strength is necessary to ensure good appearance in printing and post embossing. The offset lithographic printing process uses tacky inks, and it places a high requirement for surface strength at the point of separation between the ink left on the sheet and the ink left on the offset rubber blanket. The IGT pick and printability test simulates this process by increasing tack on a printed strip of paper or paperboard to the point of failure, which is either a surface pick or blister. Measurement of the point of failure against a specification which is known to be satisfactory provides a means of predicting a satisfactory result.

IGT pick testing is usually performed on dry paper and paperboard surfaces. However, in some circumstances it can be useful to apply a controlled quantity of water to the surface and then perform the test with a tacky ink. This is especially so for some coated substrates, where the binder system may give adequate strength when dry, but very poor strength when wetted, which has obvious implications for wet offset lithographic printing.

Embossing is a means of producing a defined design feature, pattern or texture on the surface of paper and paperboard in relief. Surface strength in the fibre, interfibre bonding and, where present, the coating are necessary to achieve the required result depending on the depth, sharpness of detail and area of the surface which is distorted.

An alternative approach to the measurement of surface strength is to apply a number of wax sticks, which are tack graded, to the surface. Tack grading relates to their ability, when molten, to stick to a flat surface. The result, Dennison Wax Number, is the highest number wax which does not disrupt the surface, when removed in the specified manner. High wax numbers indicate high surface strength. This test is only suitable for uncoated surfaces, as when a coating is present the melted wax fuses with the binder in the coating giving an unrealistic result. It can also be unsuitable for very hard sized uncoated sheets, because the molten wax is unable to stick to the surface and so gives a false indication of high strength. Nevertheless, for most uncoated surfaces, this test is relevant for both printing and adhesion.

With adhesion, it is necessary for an adhesive to pull fibre at a reasonable level of surface strength – if, however, the strength is too high it could cause poor adhesion in practice. This is relevant to adhesion with water-based adhesives, hot melts and to the adhesion of heat-sealed blister packs on heat seal-varnished and printed paperboard cards.

1.5.2.8 *Ink and varnish absorption and drying*

Inks comprise a vehicle, usually an oil, organic solvent or water, a pigment to give colour, or dye in some cases, and a resin which binds the pigment to the substrate. A varnish is similar, though without the addition of colour. The vehicle, which depends on the ink and the printing process, is necessary to transfer the ink from the ink duct or reservoir of the printing press, via the plate, to the substrate. Once printed, the vehicle has to be removed by evaporation, absorption or by being changed chemically to a solid state, so that the ink dries by oxidation or cross-linking as a result of ultraviolet (UV) or electron beam (EB) curing. Inks which are not fully dry as they leave the printing press, such as conventional oil-based litho and letterpress inks, must at least ‘set’, by a degree of adsorbency, to an extent where they do not set-off against the reverse side of adjacent sheets as they are stacked off the press.

As with most paper and paperboard properties, the key to satisfactory performance is uniformity. Lack of uniformity can lead to set-off, mottle and strike through. Tests based on the absorption of a standard ink or ink vehicle or solvent are used to check uniformity and achievement of a satisfactory specification.

Additionally, in the conventional offset lithographic process, the second colour printed in-line is transferred to a substrate which has been wetted. Under certain circumstances, this can result in print mottle, and hence a test has been devised to check ink repellency on a water-dampened surface.

Water-based sealers are increasingly displacing varnish as an after-treatment following printing. These consist of emulsified film-forming chemicals in water. They are applied by a coating unit at the end of the printing press, occasionally with an infrared drying unit directly afterwards to aid removal of the water vehicle. The emulsified chemicals film-form during evaporation of the vehicle, forming a protective layer over the ink film, which in particular virtually eliminates set-off. Various functional chemicals, such as grease-resistant materials, can be added to impart extra functionality at this stage.

1.5.2.9 *Surface pH*

For oil-based inks which dry by oxidation, a surface pH of around 6–8 is preferred. A surface pH of 5 or less is unsatisfactory as it can lead to poor ink drying with some types of ink, for example oil-based litho inks. The test is carried out by measuring the pH of a drop of distilled water using a pH electrode. This range is also important for papers or paperboards which are printed with metal pigments such as bronze and those required for laminating with aluminium foil.

1.5.2.10 *Surface tension or surface energy*

This property is important in the printing and adhesion of non-absorbent surfaces such as plastic extrusion-coated papers and paperboards. These plastic surfaces require treatment to prevent inks from reticulating. This is done by surface oxidation using an electric corona discharge or a gas flame. The effect of the treatment can be measured by checking the surface tension using Dyne measuring pens. It should be noted that the effect of such treatment reduces with the passage of time.

An alternative assessment technique is to measure the contact angle of a liquid, usually water, on the paper or paperboard surface. In this method, a small liquid droplet is applied to the substrate surface, and the shape is monitored either manually on a screen or by digital image capture. From the droplet shape, its angle of contact can be calculated. Values in excess of 90° indicate repulsion; those below 90° show attraction. Oxidative treatment of a polymer surface will generally reduce water contact angles from around 100° to 40° or below.

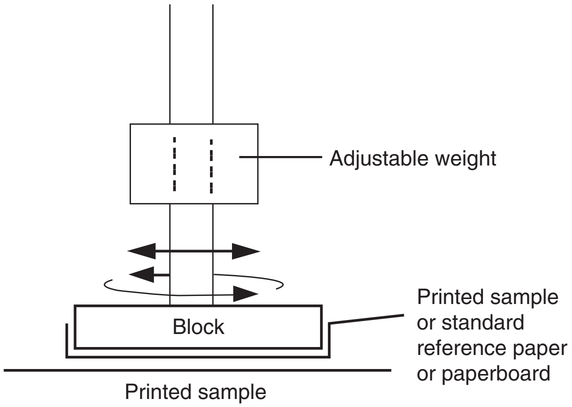

Figure 1.22 Print rub testing. (Courtesy of Iggesund Paperboard.)

1.5.2.11 *Rub resistance*

It is unacceptable for packages to be scuffed, smudged or marked in any way as a result of post-printing handling, transportation or use. Wet rub resistance is also necessary where packaging materials become wet as the result of contact with water or condensation, as is common with food packaging for products which are frozen or chilled. Good rub resistance is achieved by a combination of the paper or paperboard surface properties, the printing, varnishing or sealing process, and the formulation of the print and varnish or sealer. Rub resistance can be measured against pre-set standards using standard test methods (Fig. 1.22).

1.5.2.12 *Surface cleanliness*

A major consideration in printing is that the surface of paper and paperboard which is to be printed should be free from particles and surface dust.

Problems can be caused by loose fibres, fragments of fibres, clumps of fibres, shives (non-fibrous particles in pulp) and coating particles (Fig. 10.17). They can originate in the finishing processes of slitting and sheeting, and together with additional particles which can originate in paper and paperboard manufacture, they can cause print impression problems.

These problems are typically spots (hickies) in solid print, loss of screen definition in half-tone illustrations, ink spots in non-printing areas, etc. These problems also lead to poor efficiency in the printing operation and ultimately to waste.

There are no officially recognised methods for assessing sheet cleanliness though techniques have been developed to measure loose edge debris. Surface debris can be investigated by rolling a soft polyurethane roll over the surface and inspecting and counting particles, using magnification, from a fixed area. Wiping a surface or edge with a black cloth will also give a qualitative indication of loose material.

Whenever a problem of this nature occurs, the printer should find the particles causing the problem and identify them under magnification. Having made a correct identification, action can then be taken to eliminate or minimise the effect of the problem. It should be noted that problems of this nature may not have originated in the material. They can also arise on, or in the vicinity of, the press or as a result of problems with the inks. Hence, a correct diagnosis is essential.

1.5.2.13 *Light fastness*

Packaging is often placed in environments where it is subject to high levels of light exposure, mainly from artificial light although occasionally from direct sunlight. The paper or paperboard, printing ink and other components of the packaging should be chosen to withstand the lighting conditions expected in the storage or end-use environment. Incorrect choice can lead to fading, where the basic colours are maintained but lose their brilliance, or discolouration, which most often shows as yellowing or darkening of white areas. In either case the affected packaging will be viewed unfavourably, especially if it is shown alongside fresh unexposed material.

Paper and paperboard made from fibres which retain a high lignin content, such as mechanical wood fibre or unbleached chemical wood fibre, have poorer light fastness than sheets made from fully bleached chemical wood pulp. Other parts of the packaging, such as the inks, varnishes and sealers, and adhesives, must also be chosen to reflect the expected lighting environment into which the packaging is to be placed.

1.5.3 Performance properties

1.5.3.1 *Introduction*

Adequate performance to enable a paper or paperboard material to meet the needs of packaging manufacture and use is essential. The material must provide strength for whatever structural shape is necessary for the packaging, be it a tea bag, a label, folding carton or shipping container. Strength is necessary in printing and constructing the packaging, both in packaging manufacture, also known as conversion, and in the packaging operation, whether this is carried out manually or by machinery. Strength is also necessary for the physical protection of the goods in distribution and storage, at the point of sale and in consumer use.

Research has identified the specific features of strength and other performance needs, and tests which simulate these features have been developed so that specifications can be established. Specifications fulfil two important functions. Firstly, they provide the basic parameters for manufacture whereby paper and paperboard products are defined. Secondly, by regular testing during manufacture against the specification, the manufacturer has an accurate view of the degree of uniformity within a making and of consistency between makings. Many tests can now be performed online during manufacture, and by linking testing with computer technology a high frequency of such testing is possible. It is also possible to provide feedback within the system to automatically maintain parameters such as moisture content, thickness and grammage within the target range. This approach is also being applied to other parameters, for example colour, gloss, ash content, fibre orientation, formation and stiffness.

In testing strength and other related performance criteria, account is taken of the hygroscopic nature of the cellulose fibre, since moisture content influences most physical and optical properties of paper. The fibre absorbs moisture when exposed to high humidity and loses moisture when exposed to low humidity, so paper and paperboard will vary in moisture content depending on the RH of the atmosphere to which it is exposed.

As strength properties in particular vary with moisture content, it is necessary for specifications and test procedures to be based on samples conditioned at, and therefore in equilibrium with, a fixed temperature and RH. This is set in laboratories in Europe and

North America at 50% RH and 23°C; in tropical regions the alternative conditions are 65% RH and 27°C. It is therefore necessary to correlate specification values with the actual conditions prevailing during manufacture on the machine such that when subsequently tested after conditioning, the paper and paperboard conform with the specification.

The specific type and value of the various performance properties required will depend on the needs of the packaging concerned. Both the thinnest tissue and the thickest paperboard will have specific requirements, and the actual properties may be the same properties such as tensile strength, elongation (% stretch), tear, creasing and folding, wet strength, etc. The underlying principles and how they are achieved for each type of paper and paperboard have much in common. This is because paper and paperboard are sheet materials formed from an overlapping network of cellulose fibres. Differences in the type and value of the strength and other performance properties depend on the amount and type of fibre and its processing, whether the paper or paperboard is multilayered, together with any other ingredients, coatings or laminations which provide additional properties.

The difference between MD and CD has already been noted. Strength properties and other features show variations which are characterised by these two directions. The value of many of the test-method measurements of properties will vary depending on the direction of measurement.

1.5.3.2 *Basis weight (substance or grammage)*

The amount of material in paper and paperboard is measured as weight per unit area. In the laboratory, this is done by weighing an area of material which has been cut accurately. Basis weight is expressed in a number of ways – typically the units are grammes per square metre (g m^{-2}) or pounds per defined number of square feet. For a given paper or paperboard product, most of the strength-related properties increase with increasing basis weight.

This also has commercial implications as for a specific paper or paperboard, the higher the basis weight the lower the number of packs from a given weight of packaging material. Higher basis weight generally means more fibre per unit area, and more fibre requires the removal of more water and lower output on the paper or paperboard machine.

1.5.3.3 *Thickness (caliper)*

Thickness is measured in either microns (0.001 mm or 1×10^{-6} m) or points (1 point is 0.001 in. or one thousandth of an inch). Paper, and paperboard, is a fibrous structure; it is compressible and therefore thickness is measured with a dead weight micrometer which applies a fixed weight over a fixed area at a known rate of loading. For specific papers and paperboards, thickness increases with basis weight, and hence for a given grade, several strength properties increase with increasing thickness. However, as will be seen when stiffness is discussed, thickness can be more relevant than basis weight.

1.5.3.4 *Moisture content*

Moisture content is measured as a percentage of the dry weight. Many strength properties alter with changes in moisture content.

The cellulose fibres in paper and paperboard will expand by absorbing moisture in high RH and shrink by losing moisture in low RH conditions. The dimensions of fibres change

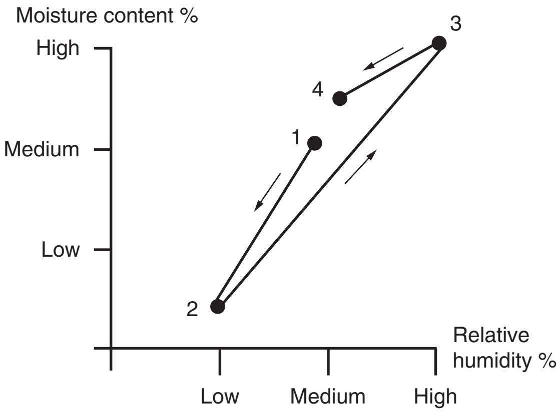

Figure 1.23 Equilibrium moisture content with RH rising (position 2/3) and RH decreasing (position 3/4 and 1/2). (Courtesy of Iggesund Paperboard.)

more in their width by swelling or contracting than they do in their length. As more fibres tend to line up in the direction of motion through the paper machine, any change in dimension across the fibres results in a greater cumulative change in the CD of the sheet. Hence, dimensional stability is more critical in the CD compared with the MD. (This can be used to determine the MD and CD of a sheet by moistening one face of a square sample where one side is parallel to an edge of the sheet. The fibres quickly swell and the moistened face expands in the CD, tending to form a cylinder, the axis of which is in the MD.)

Every paper and paperboard product will seek to achieve moisture content equilibrium with the RH of the ambient conditions in which it finds itself. This is known as hygrosensitivity. It is possible to construct curves showing how this changes over a range of relative humidities. Paper and paperboard have one set of equilibrium moisture content when the RH is rising and a different set when the RH is decreasing. This is known as the hysteresis effect (Fig. 1.23) where results are affected by previous storage conditions.

The implication of this is that the moisture content achieved in manufacture is critically important for what subsequently happens to the material in printing, conversion and use. There are therefore two aims in manufacture with respect to moisture. Firstly, a moisture content specification range which matches the equilibrium moisture content of that material over the average range of RH likely to be encountered by the product in the course of its use needs to be set. In the Northern Hemisphere, the recommended percentage of RH in which paper and paperboard are printed, converted and used on packaging lines is 45–60%. Secondly – papermakers have many techniques at their disposal to achieve this – uniform moisture content within this range during manufacture should be maintained.

The hygroscopic nature of cellulose fibre, however, also implies that the material must be adequately protected in distribution and storage. If optimum efficiency in printing, conversion and use is to be achieved, the following elements of good manufacturing practice must be observed:

- Use moisture-resistant wrappings in transit and storage.
- Follow mill recommendations with respect to storage.
- Establish temperature equilibrium in the material before unwrapping.
- Provide protection after each process.

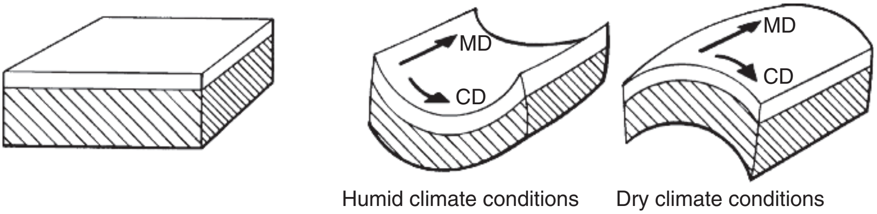

Figure 1.24 Humidity changes affect paper and paperboard flatness. (Courtesy of Iggesund Paperboard.)

Critical situations can exist when paper or paperboard is brought from a cold to a warm environment. Users should never remove moisture-resistant wrappings from paper and paperboard until the material has achieved temperature equilibrium with the room where it is to be used, for example a printing press or a packaging machine. A paperboard with a cold surface, for example after being unloaded from a lorry in winter, can cool a tacky ink, causing the tack to increase to such an extent that a severe print blister occurs during printing.

Additionally, the cold edges of a stack cool the adjacent air when moved from a cold store to a warm production area, and this can lead to the condensation of moisture on the edges. This moisture cannot be seen, but it can be absorbed, causing distortion and hence difficulty in feeding the material on a printing press or a packaging machine (Fig. 1.24). Equally, if unwrapped material is left exposed to high temperature or low humidity, it can dry out, also causing distortion.

In practice, papers and paperboards are manufactured in ways which are intended to minimise such dimensional changes (hygrosensitivity). The following of mill-recommended practices in the wrapping, storage and use of paper and paperboard by printers, converters and users are also important in order to achieve the best efficiencies in printing, conversion and use.

1.5.3.5 *Tensile strength*

The strength, or force, required to rupture a strip of the material is known as the tensile strength. The material shows elastic behaviour up to a certain point. This means that the force, or stress, applied to the strip is proportional to the deformation or elongation caused by the applied force. This is known as Hooke's Law and is expressed as:

$$\text{Stress (applied force)} = \text{Constant } (E) \times \text{Strain (dimensional change)}$$

This constant is known as the modulus of elasticity (E) or Young's modulus.

Up to a certain point, paper and paperboard show elastic properties (Fig. 1.25). This means that if the force is removed, the sample will regain its original shape – however, above the elastic limit this no longer applies as the material increasingly undergoes plastic deformation until it ruptures.

Specifications are based on test methods with fixed strip widths and rates of loading – the tensile strength being recorded as force per unit width. Tensile strength is higher in the MD compared with the CD.

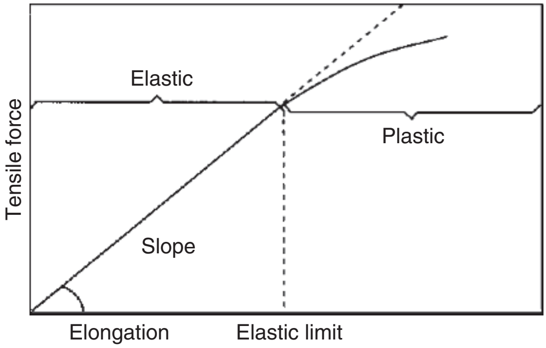

Figure 1.25 Stress–strain relationship showing elastic and plastic properties. (Courtesy of Iggesund Paperboard.)

For substrates that are to be used in the presence of liquids, wet strength resins (Section 1.2.6) may be added, in which case wet tensile strength should also be measured. In this test the strip is soaked in liquid, usually water, until it is saturated, then a tensile test is performed. The strength retention when saturated, expressed as a percentage of the original dry tensile strength, is then recorded. Typical wet-strengthened papers retain a minimum of 15% of their dry strength when fully saturated.

The tensile value at the point of rupture will vary with the rate of applying the load. When the load is steadily increased the measurement is referred to as a static tensile, and when the load is applied suddenly over a very short time interval, the measurement is referred to as a dynamic tensile.

The latter, defined as tensile energy absorption (TEA), is important in understanding the paper properties which relate to the drop-test performance of a multiwall paper sack. This test is a measure of the work done, i.e. force × distance, to rupture the sample, and it combines the features of tensile strength and percentage stretch.

1.5.3.6 *Stretch or elongation*

This is the maximum elongation of a strip in a tensile test at rupture and is a measure of elasticity expressed as a percentage increase compared with the original length between the clamping jaws. CD elongation is higher than MD elongation, unless the material has been creped.

1.5.3.7 *Tearing resistance*

Tearing resistance (Fig. 1.26) is the measured force required to promulgate a tear in the sheet from an initiated cut. In most situations, the need is to prevent damage by tearing. In some cases as, for instance, with a tear strip to facilitate opening a pack and gaining access to the contents, the requirement is for the material to tear cleanly.

1.5.3.8 *Burst resistance*

To test for burst resistance, the sheet is clamped over a circular orifice and subjected to increasing hydraulic pressure until expansion of a rubber diaphragm causes rupture (Fig. 1.27). It is a simple test to perform but its relevance to strength in practice is complicated. High

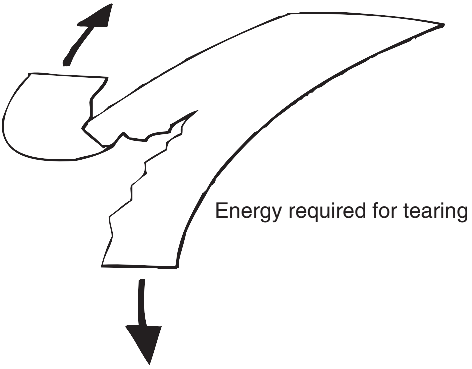

Figure 1.26 Principle of tearing resistance. (Courtesy of Iggesund Paperboard.)

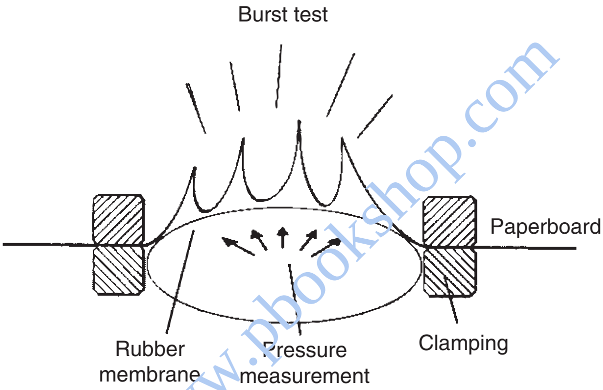

Figure 1.27 Principle of burst resistance. (Courtesy of Iggesund Paperboard.)

values, however, indicate toughness. As noted in Section 1.2.6, wet strength resins can be added at the stock-preparation stage to enable the paper to retain a significant proportion of its dry strength if it becomes wet during subsequent usage. The extent of wet strength is calculated by comparing the dry burst strength with the burst strength after the sample has been wetted in a specified way. The percentage of wet burst to dry burst expresses the extent of strength retention when wet.

1.5.3.9 *Puncture resistance*

Puncture resistance testing follows a similar process as that for burst resistance, although the penetrating probe is very different; also, the test is only suitable for heavyweight material, such as paperboard. The test sheet is clamped over an orifice and a pointed projectile attached to a heavy sector is swung so that the point contacts and penetrates the paperboard. The loss in potential energy, determined by the extent to which the sector continues to swing after contacting the test material, is a measure of the energy expanded in penetrating the sheet.

1.5.3.10 *Stiffness*

This property has major significance in printing, conversion and use. Stiffness is defined as the resistance to bending caused by an externally applied force. Stiffness of lightweight

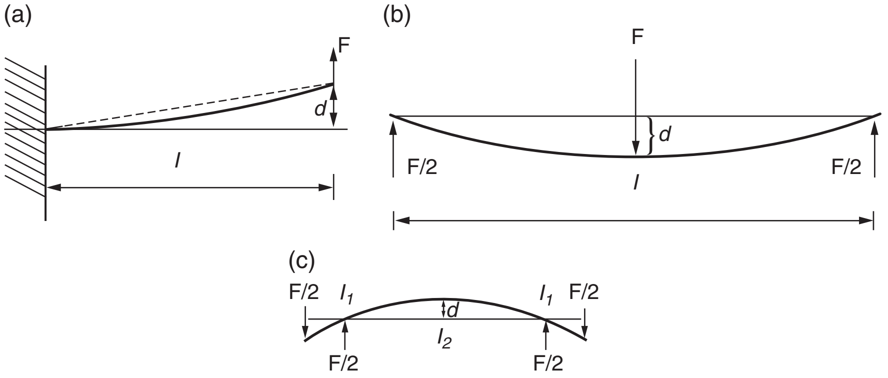

Figure 1.28 Loading principles for the measurement of paper and paperboard stiffness by the (a) two-, (b) three- and (c) four-point methods.

materials is measured by applying a force (*F*) to the free end of a fixed size piece of the material, length (*l*), which is clamped at the other end, and deflecting the free end through a fixed distance or angle (δ). This is known as the two-point method (Fig. 1.28). It is used to measure bending stiffness, bending resistance and bending moment.

For heavyweight or thick materials, the two-point method causes crushing, even at low-bending angles, which results in anomalously low stiffness values. For these materials, three-point (Fig. 1.28) or even four-point (Fig. 1.28) methods are preferred (Markström, 1988; Müller, 2011).

The MD stiffness value is higher than the CD value, and sometimes this is expressed as the stiffness ratio, i.e. MD stiffness/CD stiffness. This difference is the result of the differing fibre alignment arising as a result of the method of manufacture. Stiffness is also related to other important features, such as box compression, creasability, foldability and overall toughness. An important consideration regarding stiffness is that it is related to the modulus of elasticity (*E*) and thickness (*t*) (caliper) as follows:

$$\text{Stiffness} = \text{Constant (material specific)} \times E \times t^3$$

The cubic relationship is valid for homogeneous materials providing that the elastic limit is not exceeded. For paper and paperboard, the index is lower than 3.0 but is still significant. For some types of paperboard the index is around 2.5–2.6. Thus it is valid to claim that stiffness is highly dependent on thickness as is shown by doubling the thickness and noting that the stiffness increases by a factor of just over five.

1.5.3.11 *Compression strength*

When we discuss compression in the context of packaging needs, we usually mean the effect of externally applied loads in the storage, distribution and use of packed products in packaging such as cartons, cases and drums.

We can study the effect on compression of different aspects of pack design, different types and thicknesses of paper and paperboard, and different climatic conditions. We recognise the difference between static loads applied over long periods, as with palletised loads in storage, and the dynamic loads associated with high forces applied for very short periods, as in dropping and with transport-induced shocks. So we carry out compression tests on the packs at different rates of loading.

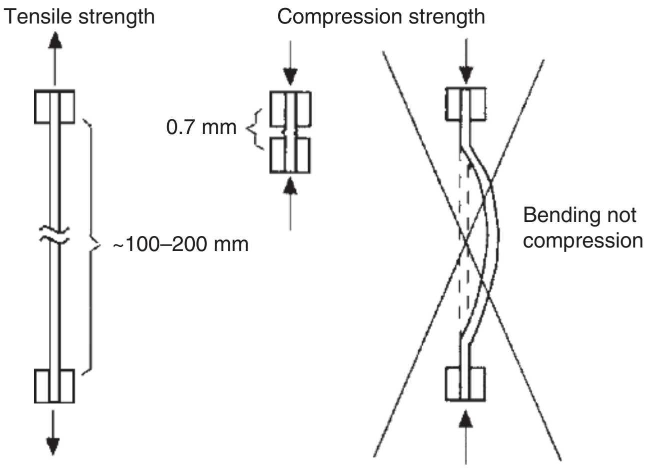

Figure 1.29 Compression strength testing – note difference in sample length compared with the tensile test. (Courtesy of Iggesund Paperboard.)

Research has shown that the inherent paper and paperboard properties involved in box compression are stiffness, as already discussed, and what is known as the short-span compression strength.

When an unsupported sample of paper or paperboard is compressed by applying a force to opposite edges in the same plane as the sample, the material will, not unexpectedly, bend. This does not give a measure of compression strength (Fig. 1.29). If, however, the sample height in the direction of the applied force is reduced below the average fibre length, say to 0.7 mm, the force is then applied to the fibre network in such a way that the network itself is compressed causing the fibres to move in relation to each other. In this situation, interfibre bonding and the type(s) and quantity of fibre become important to the result which we call the 'short-span compression strength'. It is this inherent characteristic of the sheet, in the direction of measurement, MD or CD together with stiffness, which relates to box compression strength.

Further specialist compression tests, related to corrugated board, are discussed in Chapter 11.

1.5.3.12 *Creasability and foldability*

Paper and paperboard are frequently folded in the construction of pack shapes such as many designs of bags and sachets, cartons and corrugated and solid fibreboard cases. The thinner materials are folded mechanically through 180° and the resulting folds are rolled to give permanence. The thicker materials for cartons and cases require a crease to be made in the material prior to folding.

The material to be creased is supported on a thin sheet of material known as the make-ready, or counter die, which itself is adhered to a flat steel plate. Grooves are cut in the make-ready to match the position of the creasing rules in the die. When the die is closed, creases are pressed into the surface, creating a groove in the surface of the carton and a bulge on the reverse side. Crease forming in this way subjects the material to several forms of stress which are indicated in Fig. 10.29.

When the crease is folded, the top layers of fibre on the outside of the resulting fold are extended and therefore require adequate tensile strength and stretch. The internal layers are

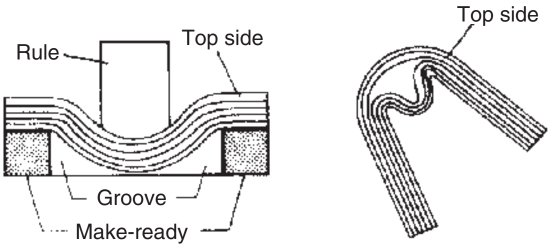

Figure 1.30 Crease forming and folding. (Courtesy of BPIF Cartons.)

compressed causing localised delamination (Figs 10.30, 10.31 and 10.32). The reverse side bulge in turn develops as a bead as folding continues to the desired angle and thus behaves like a hinge (Fig. 1.30). It is important that the bulge itself does not rupture or become distorted. Hence the layer of fibre on the reverse side also requires good strength properties.

In addition to good strength properties in the material, the geometry of the creasing operation – i.e. the width of the creasing rule, width and depth of the make-ready groove and the penetration of the creasing rule into the surface of the material – is most important. In addition to the visual inspection of creases and folds, it is also possible to measure resistance to folding and spring-back force – features which can be controlled by the creasing geometry.

In a laboratory, creasing and foldability can be assessed using either a commercial hand-creasing apparatus or a PATRA crease tester. The most basic commercial hand crease apparatus has a single fixed creasing rule and a single groove (channel); those apparatus which allow the rule and channel to be altered are preferable, as these should be chosen to suite the substrate under test. The PATRA crease tester is a very heavy and solid test instrument that encompasses the ability to use several rules and channels. Whichever apparatus is used, the test involves forming a crease, then folding the material by hand and assessing whether any cracking of the surfaces occurs.

The subsequent performance of carton creases folded during gluing is time dependent. This is important where side seam-glued cartons are stored before use on a cartonning machine. This feature can be measured as ‘carton opening force’. The conditions of such intermediate storage in terms of humidity, temperature, tightness or looseness of packing and the stacking of the cases in which the cartons are stored are also important factors which can affect efficiency in packaging operations.

1.5.3.13 *Ply bond (interlayer) strength*

Ply bond strength (Fig. 1.31) is important for multilayered paper and paperboard products. It relates to the delamination of the material when subjected to forces perpendicular to the plain of the material, which cause delamination. The delaminating force is measured with the help of metal plates or platens which are attached to the paperboard surface by means of double-sided self-adhesive tape. In the TAPPI test, the platens are gripped in the jaws of a tensile tester and pulled apart; the rate of testing is relatively slow and the failure equates of a plastic yield between the plies. An alternative method is the Scott Bond test, where a pendulum strikes one metal plate, causing almost instantaneous delamination; the force transfer is rapid, and this produces an elastic failure. The two test methods tend to yield very different information.

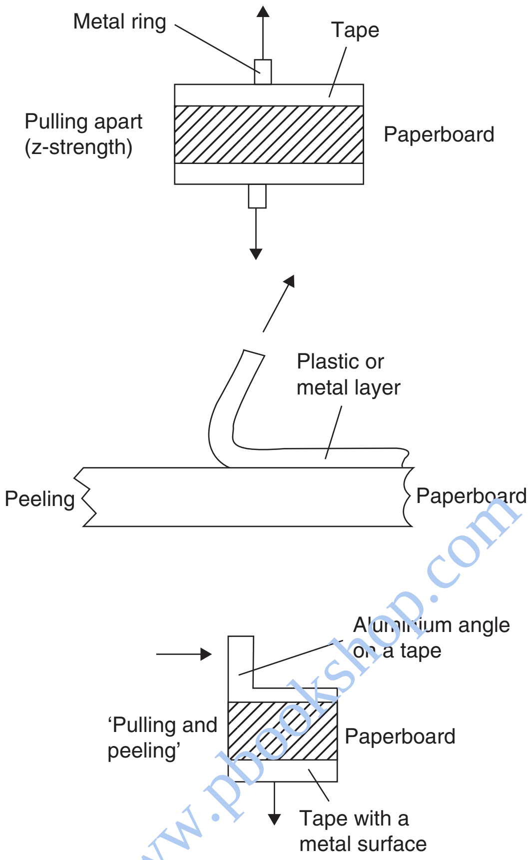

Figure 1.31 Principles of testing interlaminar strength. (Courtesy of Iggesund Paperboard.)

If delamination strength is too low, adhesive bonds may fail too easily, and if too high, the internal delamination necessary for good creasing will not occur.

1.5.3.14 *Flatness and dimensional stability*

Flatness is important in the sheet of paper or paperboard for its efficiency both in printing and conversion and subsequently at the packing stage. Examples of the type of problems which can occur are misfeeds, which cause stoppages, and mis-register of colour to colour and print to profile. The flatness required is built into the material during paper or paperboard manufacturing. Variations in forming, tension, drying and moisture content can cause wave, curl, twists, cockle and baggy patches (Fig. 1.32).

As discussed in Section 1.5.3.4, the hygroscopic nature of cellulose fibre requires that the material must be adequately protected in distribution, storage and use. There are requirements of good manufacturing practice which must be observed if optimum efficiency in printing, conversion and use is to be achieved. As noted, these are to do with the use of moisture-resistant wrappings, achieving temperature equilibrium before unwrapping and rewrapping where paper or paperboard is liable to be affected by storage in either high or

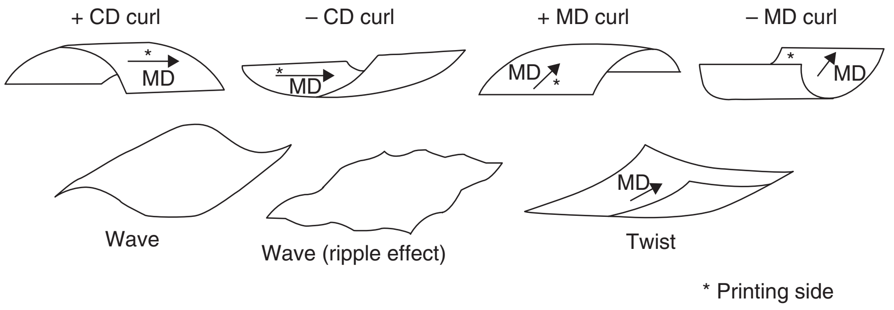

Figure 1.32 Different types of curl, twist and wave. (Courtesy of Iggesund Paperboard.)

low RH conditions. Critical situations can exist when paper or paperboard is brought from a cold to a warm environment and where the RH range is outside 45–60%.

1.5.3.15 *Porosity*

Uncoated papers and paperboards are permeable to air. This property is assessed using instruments that force or suck air through a defined area of sheet, using a fixed pressure. There are two main methods that measure related but distinct properties: *air resistance* measures the time taken for a fixed volume of air to pass through a sheet (e.g. Gurley) and *air permanence* measures the volume to pass per unit time (e.g. Bendtsen or Sheffield). High values of air resistance equate to low values of air permanence.

This property has implications for situations where the material is picked up by a vacuum cup so that it can be moved to another position. This occurs on printing presses, cutting and creasing machines and packaging machines. Variable porosity outside specified limits can lead to more than one sheet or piece of packaging being picked up, which, in turn, can jam the machine.

Problems can also occur when coated materials are incorrectly picked up by vacuum cups from the uncoated reverse side surface when air can be drawn in from the adjacent raw edge of the material. This, however, is a problem of either machine setting or an incompatibility between the pack design and the machine setting.

Porosity is an important factor in the speed of filling of fine powders in multiwall paper sacks where it is necessary for air to escape from the inside of the package.

1.5.3.16 *Water absorbency*

There are occasions when water comes in contact with paper and paperboard materials – this may happen deliberately as when water-based adhesives are used or in an unplanned way as for instance when moisture condenses on the surfaces and cut edges of a carton removed from a frozen-food cabinet at the point of sale.

Water absorbency is dealt with in one of two ways or a combination of both. Firstly, by internally sizing, whereby a water-repellent material (size) is incorporated at the stock or pulp preparation stage just prior to introducing the stock to the paper or paperboard machine. Many types of paper and paperboard are sized as part of normal production, but where a higher degree of water hold-out is required, extra hard sizing is added to the stock. In multilayer paperboards this means that each layer, including the middle layers, is hard sized.

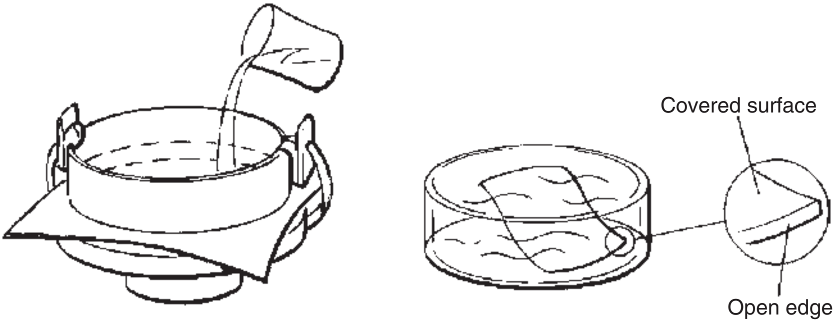

Figure 1.33 Cobb and wicking tests. (Courtesy of Iggesund Paperboard.)

The size, which may be either of natural origin (rosin) or synthetic, is deposited on the surface of the cellulose fibres making them water repellent. Secondly, a surface coating can be applied during manufacture either as a surface size or as a separate coating operation, as would be the case with an extrusion coating of PE or where a varnish or sealer is applied over print.

The simplest method of measuring the water absorbency of flat surfaces is by the Cobb test method (Fig. 1.33), which measures the weight of water absorbed in a given time over a given area. Usually the time interval is either 1 or 3 min. A note of caution must be stated that whilst this seems an obvious and suitable method of testing, it does not always correlate with what happens in practice. This is mainly due to different, usually shorter, time intervals or dwell times where water-based adhesives are held under pressure on packaging machines and where tack develops as a result of some of the water being adsorbed. However, in many cases it is an indication of functional performance.

Water can also enter through the exposed cut edges of packaging. This can also be retarded by hard sizing. The flat surfaces of samples for this test are sealed with waterproof plastic adhesive tape prior to weighing the sample and immersing it in water for the stipulated time.

1.5.3.17 *Gluability/adhesion/sealing*

The principles of adhesion and gluability apply in many situations where materials incorporating paper and paperboard are joined together. This occurs, for instance, when side seams are required for bags, cartons and cases and when packs are closed after filling. It is also relevant to lamination with adhesives, the manufacture and use of labels, plastic-extrusion coating and heat sealing.

The adhesives (glues) are usually either water-based with a bonding material solids content of 50–60%, where the water acts as a carrier, or wax/polymer blends which are 100% solid and applied hot in the molten state. In heat sealing, the plastic incorporated in or on the surface of the material acts as the adhesive.

Adhesion is characterised by three stages:

- open time for the adhesive to remain functional after being applied to one surface and before the joint is made
- setting time during which it is necessary to keep the joint under pressure
- drying time is the time necessary to develop a permanent bond.

Adhesives are chosen to suit the surfaces being joined, the constraints of the operation in respect of open, setting and drying times, and any special functional needs of the pack and its use, for example wet strength, direct food contact approval, etc.

A good glue bond, where at least one of the surfaces is paper or paperboard, must show fibre tear at a satisfactory strength when peeled open. Where the adhesive is applied to the surface, it must ‘wet’ or flow out evenly over the area of application.

Some paper and paperboards are extrusion coated with plastics such as PE on one or two sides. Packs incorporating such materials may be sealed by heat sealing either by sealing plastic to paper, as an overlap seal, or plastic to plastic. The plastic is softened and becomes tacky/molten under heat and pressure and then cools and resolidifies forming a strong seal. A strong heat seal also requires good fibre tear in the paper or paperboard material. With multilayer thicker materials, such as paperboard, the fibre tear must rupture the *internal* layers when the seal is peeled open.

Heat-sealable tea-bag tissue incorporates a heat-sealing medium such as PP in the form of a fibre dispersed within the very thin sheet.

1.5.3.18 *Taint and odour neutrality*

Some products are sensitive to changes in their taste, flavour or aroma. Examples are fat-containing food products, such as butter, vegetable fats and chocolate. Other flavour- and aroma-sensitive products are tea and coffee and a range of tobacco products. Changes can occur by loss of flavour through the packaging, the ingress of unwanted flavours from the external environment and by the transfer of flavours originating in the packaging. The first two potential causes are prevented by augmenting the paper and paperboard with additional barrier materials, such as aluminium foil, a metallised coating on plastic film, PVdC-coated OPP film, etc. Whilst all packaging associated with flavour- and aroma-sensitive products has to meet critical requirements, here we are concerned with aspects which potentially can apply to paper and paperboard packaging.

The best approach is to ensure that when odour and taint critical packaging is required, the raw materials are chosen carefully. The range of paper and paperboard materials is wide and depending on the needs of the product, many papers and paperboards can be ruled out initially from what is known, doubtful or potentially variable about their constituents.

For the most critical products virgin fibre is necessary; recycled fibre can contain a very wide range of materials, some of which are volatile and can give rise to odour and taint. The best results are achieved with chemically separated and bleached virgin pulp. For some critical products, paperboard with a mixture of this material and mechanically separated virgin pulp has also been approved and is used widely. The concern with these materials is not the pure cellulose fibre, which is inert and odourless, but other residual wood-originating compounds which may not be fully removed by bleaching and which are either not removed or only partially removed in the case of mechanical pulp. The pulp can contain residual fatty acids from the wood, and these compounds are oxidised over time producing odoriferous aldehydes.

Another potential source of odour and taint can be residual compounds originating from the chemicals which are used for the mineral coating – not so much the mineral compounds themselves but the synthetic binders (adhesives) which bind the particles together and to the base sheet of fibre.

Paper and paperboard-based packaging for use with products which have critical odour- and taint-free requirements can be checked by panels of selected people using sensory methods based on smelling and tasting. Where odour or taint is detected, the compounds responsible can be identified by gas chromatography and mass spectrometry. The concentration of compounds can be measured by gas chromatography, see Section 10.8. Many other potential sources for odour and taint arise as the result of printing, varnishing and other conversion processes.

1.5.3.19 *Product safety*

The basic requirement of packaging is that it should ensure the quality of the packed product however that is defined in the geographical areas of the world and the end uses involved. In some cases, this leads to the need for assurances regarding the safety of food in direct contact, or close proximity, to specific packaging materials. It also leads to a similar need with respect to the packaging used for toys.

These needs are defined in compliance regulations. In the USA, the regulations are given in the 'Code of Federal Regulations, Food and Drugs Administration (FDA)'.

In the USA, there are also the CONEG (Confederation of North Eastern Governors) Regulations which set limits for the content of lead, mercury, cadmium, chromium and nickel in packaging materials, such as paper and paperboard, in direct contact with food.

In Europe, the most widely quoted are those formulated in the 'Bundesgesundheitsamt (BGA)'. The work we are concerned with here became part of the German Federal Institute for Consumer Protection and Veterinary Medicine Regulations or BgVV in 1994 and then by the BfR (Federal Institute for Risk Assessment – Bundesinstitut für Risikobewertung) in 2002 (Heynkes, 2007). In Holland there are the 'Warenwet' regulations.

Paper and paperboard has a long and successful history of safe use in the food industry in a wide range of applications. These include applications where intimate contact is involved, such as tea bags, baking papers and filters, and direct contact packaging such as butter wrapping, sugar bags and cartons for dry and frozen foods. In addition, it has a very wide range of uses in transport and distribution packaging (CEPI, 2010).

The European Union has Directives, 76/893/EEC and 89/109/EEC, and a Regulation, 1935/2004/EC. These documents make provision for future Directives relating to specific materials, such as plastics, 2005/70/EC, but so far does not have a Directive relating to paper and paperboard, although, as already indicated, there are national provisions which paper and paperboard makers can meet.

Therefore, CEPI, CITPA (The International Confederation of Paper and Board Converters in Europe), FPE (Paper and board multilayer manufacturers) and CEPIC (Suppliers of Chemicals) worked together and developed a report which was published in March 2010 by CEPI and CITPA entitled *Industry Guidance for the Compliance of Paper & Board Materials and Articles for Food Contact* (CEPI, 2010). This is a voluntary guideline to obtaining compliance with current European food contact legislation, but it could form the basis for a specific directive in the future.

The substances permitted for use in paper and board conforming with this guideline are given in BfR Recommendation XXXVI 'Paper and Board for Food Contact'. This is an evolving subject and readers are advised to seek the latest position from manufacturers and suppliers at any given time.

For toy packaging, the regulations are embodied in EN71 Part 3 8126-3-1997 (limits to the migration of certain elements).

Where plastic coatings are involved with paper and paperboard in direct food contact, they are expected to meet the EC Plastics Food Packaging Directive 2005/70/EC and its amendments. The regulations applying to plastics concern numerous specific migration limits originating from the wide range of plastics and the materials they contain and come into contact with. Paper and paperboard is significantly different in that it mainly comprises the naturally originating polymer-based cellulose fibre and naturally occurring minerals such as calcium carbonate and natural polymers such as starch. Very small amounts of chemical additives such as sizing are used to achieve specific effects, and other chemicals, which are ultimately washed out, are used to facilitate the papermaking process.

Mills can give assurances showing that they meet the requirements of EU Regulation 1907/2008/EC (REACH or the Registration, Evaluation and Authorisation of Chemicals) which in terms of the paper and paperboard product guarantee that the content of SVCH (substances of very high concern) is lower than the stipulated limit of 0.1% in accordance with article 57 in the regulation.

Users of packaging can show diligence in ensuring that regulations are met by requiring evidence from suppliers to show which approved laboratories have checked that the materials concerned meet the appropriate regulations.

1.6 Specifications and quality standards

Having examined the appearance and performance properties of paper and paperboard packaging materials, it is clear that considerable efforts have been made to relate them to packaging needs. Test procedures which measure these properties and relate them to market needs have been developed and used in specifications.

Specifications are needed for a variety of reasons – communication of exact needs, quality assessment, resolving disputes, compatibility of competing quotations and as a basis for improvement.

The paper and paperboard market is international with pulp, paper and packaging traded on a worldwide basis. Hence there has been a need for harmonisation of test methodology. Test methods are developed locally and between suppliers and customers on a one-to-one basis. These may become national standards such as British Standards (BS), German Standards (DIN) and TAPPI in North America. In recent years, international standards have been developed through the ISO.

Tolerances which are realistic are an important requirement of specifications. Over time, the needs and expectations of customers increase – equally the abilities and achievements of suppliers have to respond to market needs. Online computer control has, in many cases, augmented laboratory testing, which by its nature is historical. This development which is progressive and ongoing results in less variability within makings and between makings, and less variability leads to higher productivity.

Equally important is the requirement that quality management systems overall must be seen to be effective. Many manufacturers now have their quality systems independently and regularly assessed under the ISO 9000 series of Quality Standards. Supplier audits are also undertaken.

1.7 Conversion factors for substance (basis weight) and thickness measurements

It will already have been noted, for example in Sections 1.5.3.2 and 1.5.3.3, that different conventions are used in different parts of the world for the measurement of basis weight and thickness.

It is, however, possible to convert measurements in one convention to another as follows:

$$\text{Substance}\left(\text{basis weight}\right)\ \text{measured in lb}/1000\,\text{ft}^2 = 4.882\,\text{g}\,\text{m}^{-2}\left(\text{grammage}\right)$$

$$\text{Substance}\left(\text{basis weight}\right)\ \text{measured in lb}/3000\,\text{ft}^2 = 1.627\,\text{g}\,\text{m}^{-2}\left(\text{grammage}\right)$$

$$\begin{aligned}&\text{Thickness measured in `thou'}\left(\text{thousandths of an inch}\right)\\&\quad= 25.4\ \text{micron}\left(\text{thousandths of a millimeter}\right)\end{aligned}$$

A thousandth of an inch is also known as a ‘point’ and, in the case of plastic film thicknesses, as a ‘mil’. The SI symbol for a micron, or micrometer, is ‘µm’.

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