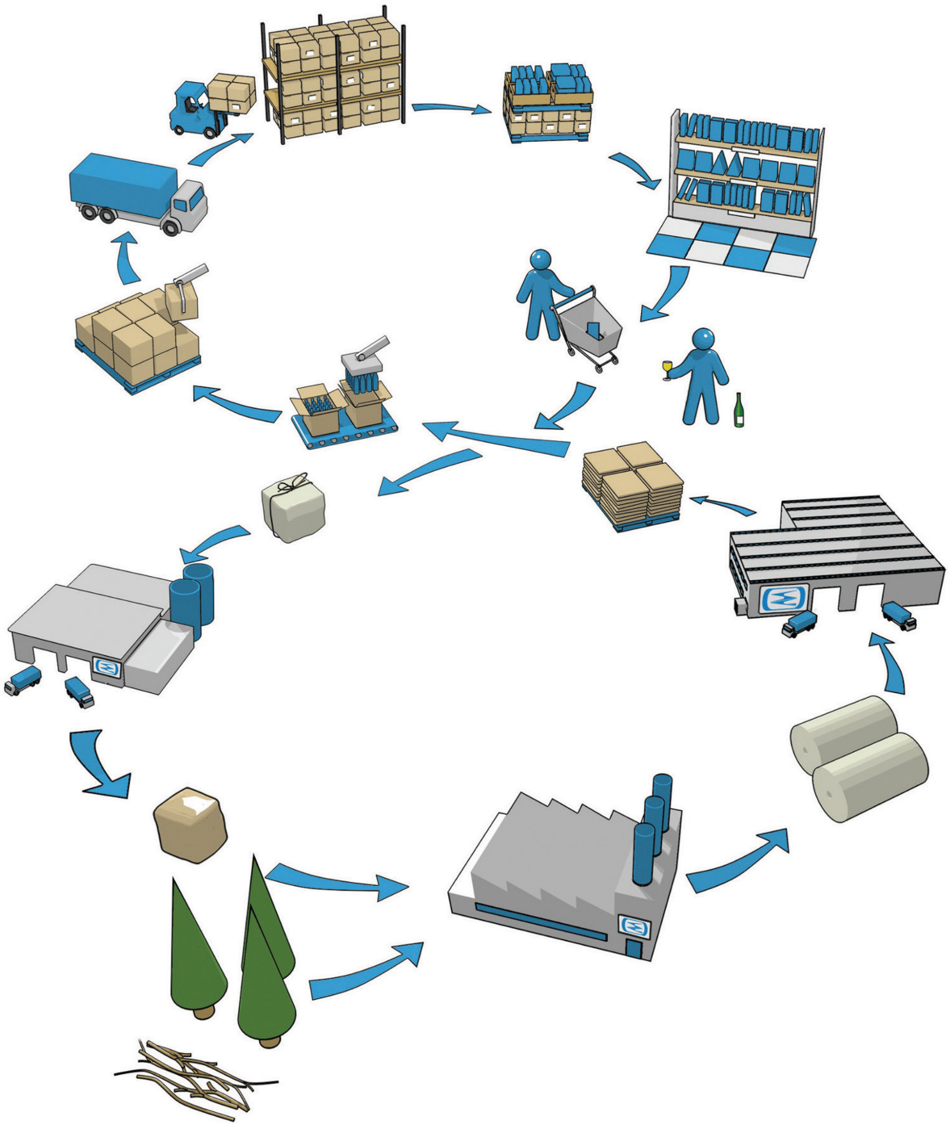
Handbook of Paper and Paperboard Packaging Technology

SECOND EDITION

Edited by Mark J. Kirwan



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Preface

This book discusses all the main types of packaging based on paper and paperboard. It considers the raw materials and manufacture of paper and paperboard, and the basic properties and features on which packaging made from these materials depends for its appearance and performance. The manufacture of 12 of the main types of paper- and paperboard-based packaging is described, together with their end-use applications and the packaging machinery involved. The importance of pack design is stressed, including how these materials offer packaging designers opportunities for imaginative and innovative design solutions.

Authors have been drawn from major manufacturers of paper- and paperboard-based packaging in the UK, the Netherlands, Austria and the USA, and companies over a much wider area have helped with information and illustrations. The editor has wide experience in industry having spent his career in technical roles in the manufacture, printing, conversion and use of paper, paperboard and packaging.

Packaging represents the largest usage of paper and paperboard and therefore both influences and is influenced by the worldwide paper industry. Paper is based mainly on cellulose fibres derived from wood, which in turn is obtained from forestry. The paper industry is a major user of energy and other resources. The industry is therefore in the forefront of current environmental debates. This book discusses these issues and indicates how the industry stands in relation to the current requirement to be environmentally sound and the need to be sustainable in the long term. Other related issues discussed are packaging reduction, life-cycle analysis and assessment, and the options for waste management.

The book is directed at those joining companies which manufacture packaging grades of paper and paperboard, companies involved in the design, printing and production of packaging and companies which manufacture inks, coatings, adhesives and packaging machinery. It will be essential reading for students of packaging technology in the design and use of paper- and paperboard-based packaging as well as those working in the associated media.

The ‘packaging chain’ mainly comprises:

- Those responsible for sourcing and manufacturing packaging raw materials.
- Printers and manufacturers of packaging, including manufacturers of inks, adhesives, coatings of all kinds and the equipment required for printing and conversion.
- Packers of goods, for example within the food industry, including manufacturers of packaging machinery and those involved in distribution.
- The retail sector, supermarkets, high street shops, etc., together with the service sector, hospitals, catering, education, etc.

The packaging chain creates a large number of supplier/customer interfaces, both between and within companies, which require knowledge and understanding. The papermaker needs to understand the requirements of printing, conversion and use. Equally, those involved in printing conversion and use need to understand the technology and logistics of papermaking together with the packaging needs of their customers and society. Whatever your position within the packaging chain, it is important to be knowledgeable about the technologies both upstream and downstream from your position.

Packaging technologists play a pivotal role in defining packaging needs and cooperating with other specialists to meet those needs in cost-effective and environmentally sound ways. They work with suppliers to keep abreast of innovations in the manufacture of materials and innovations in printing, conversion and use. They need to be aware of trends in distribution, retailing, point-of-sale/dispensing, consumer use, disposal options and all the societal and environmental issues relevant to packaging in general.

Acknowledgements

My thanks go to the contributing authors and their companies. It is not easy these days to find time for such additional work, and their contributions are much appreciated.

The text has been greatly enhanced by the diagrams kindly provided by a large number of organisations and by the advice and information that I have received from many individuals in packaging companies and organisations involved in the paper, paperboard, packaging and allied industries.

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This book would not have been attempted without the experience gained in my packaging career, for which I thank former colleagues at Reed Medway Sacks, Bowater Packaging (carton, paper bag and flexible packaging manufacture), Cadbury Schweppes (foods packaging), Glaxo (ethical and proprietary pharmaceuticals packaging), Thames Group (paperboard manufacture) and, in particular, Iggesund Paperboard, who encouraged me to become involved in technical writing.

In helping me to complete this second edition, I acknowledge the consistent help I have received from Richard Coles (Open University and Greenwich University), who involved me in lecturing on packaging technology at B.Sc. and Institute of Packaging Diploma level at West Herts College, Watford, UK, and Daven Chamberlain, Editor of *Paper Technology*, whom I have also known for many years and who has a wide technical background in the paper industry.

I am indebted to Professor Frank Paine, who stimulated my interest in producing this book in the first place, for his cheerful support and encouragement over many years. I first met Frank as a colleague in Bowater in the 1960s. He has 60 years of international experience in packaging technology research and practice and substantial experience in authorship and editing.

I would like to dedicate this book to the memory of my former colleague, Richard Slade (Findus and Cadbury Schweppes), who involved me in packaging development from the 1960s onwards, and to that of Dennis Hine, who led, lectured and wrote about much of the investigative work on carton performance and packaging machine/packaging materials interactions at Pira International over many years.

Mark J. Kirwan

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

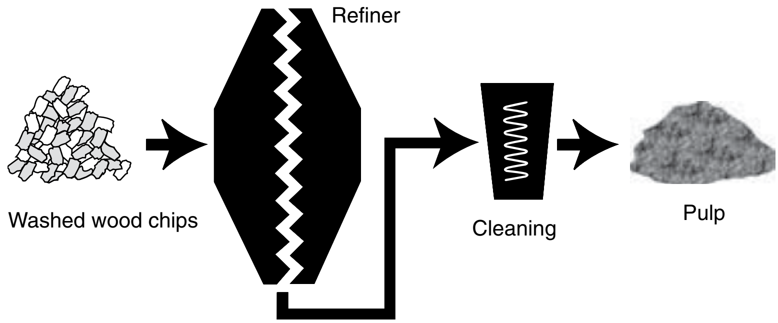

Figure 1.1 Production of mechanically separated pulp. (Courtesy of Pro Carton.)

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