PAPER PACKAGING TRAINING

Content

I. Paper & Paperboard

1.1. The classification of paper and paperboard

1.2. The manufacture processes

1.2.1. Raw material and additives

1.2.2. Fibre separation from wood (pulping)

1.2.3. Post-pulping treatment of fibres to improve performance

1.2.4. Manufacture on the paper or paperboard machine

1.2.5. Control of quality of paper and paperboard

II. Paper and Paperboard Packaging

III. Corrugated Board Packaging

3.1. Structure of corrugated fibreboard

3.2. Manufacturing process

3.2.1. Overview and materials for corrugated board production.

3.2.2. Corrugated board production

3.2.3. Corrugated board printing

3.3. Testing corrugated board materials and packaging

3.3.1. Typical test method for corrugated board

3.3.2. Test methods for Box

3.3.3. Different types of corrugated board container design

I. Paper & Paperboard

1.1. The classification of paper and paperboard

“Paper” or “Paperboard” can be described as a matted or felted sheet, usually composed of plant fibre (commonly from trees or recycled paper or paperboard waste). It can also be made from others fibrous materials such as linen, sugar cane, cotton and the stalks of cereal plants such as corn (commonly known as straw).

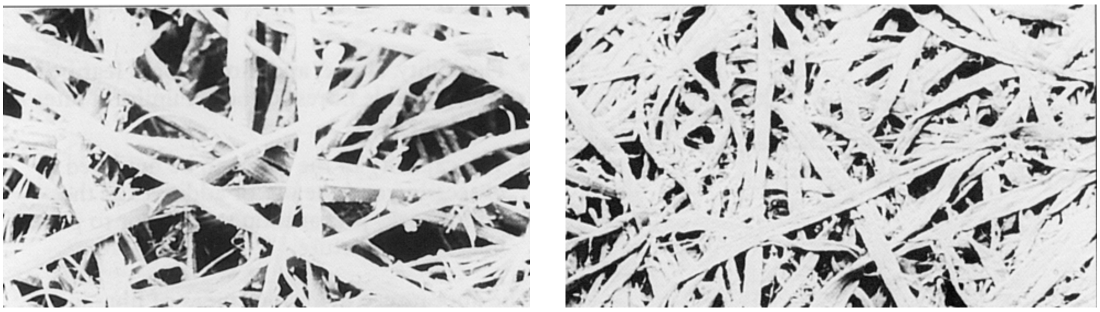


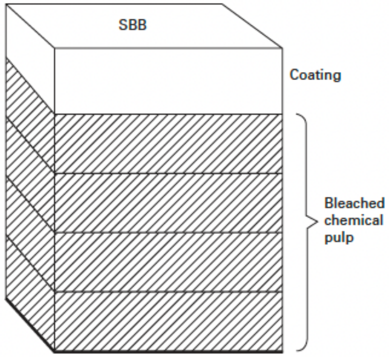
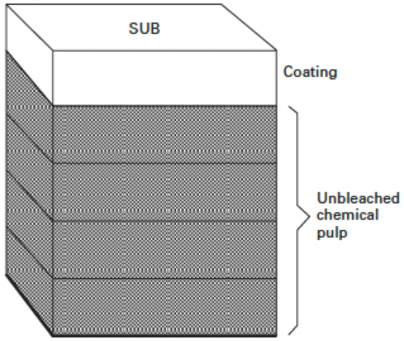
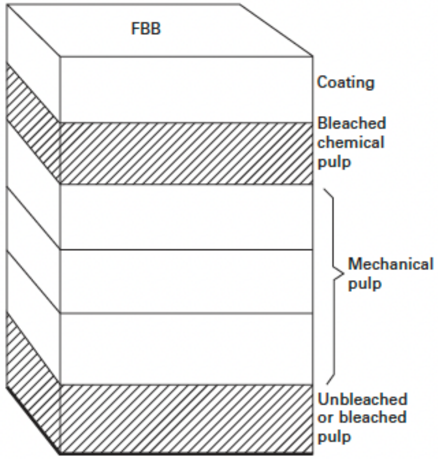
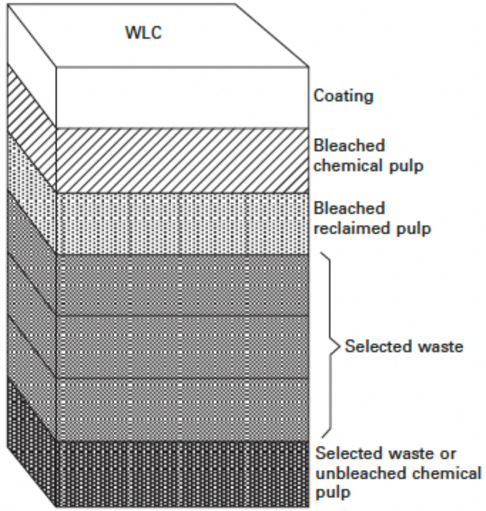
__Figure 1__ - Matted fibres (mechanical pulp) and Matted fibres (chemical pulp)

They are the most common packaging raw materials and is defined by the ISO as its substrate with “Paper” made from vegetable fibres, which has a grammage (basic weight) of less than 225 grams per square metre (gsm). “Paperboard” (also known as cartonboard, cardboard, boxboard or just board) has a grammage of 225 gsm or over. This definitive difference, however, is not widely used within the industry, different countries using varying terminology.

Paper is used mainly in corrugated board manufacture, spiral tube making, and also in laminates, sack and bag manufacture, and wrapping material for such product as ream-wrap for copier paper. Paperboard is used mainly in cartons and grades of them used can be generally classified as follows.

The DIN 19303 standard for classification of paperboards is a little more refined than the traditional terminology used in the United States and the United Kingdom.

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

Paperboard Structure				
Description	Solid bleached board (SBB), made from virgin bleached chemical pulp, has a mineral pigment-coated top surface or also on the back.	Solid unbleached board (SUB) made mainly from unbleached virgin chemical pulp. A layer of bleached fibre is sometimes added to the top to provide greater whiteness	Folding boxboard (FBB) 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 and the bottom layer can be either bleached or unbleached virgin chemical pulp	White lined chipboard (WLC) made from multi-layers of recycled fibres. The top layer can be made from bleached virgin chemical pulp or white de-inked recycled fibres. Between the top layer and the middle layer(s) there can be a layer of chemical, mechanical or deinked recycled fibres. The bottom layer can be made from selected recycled or bleached and/or unbleached virgin fibres
Advantage	This paper has excellent surface and printing characteristics., it gives wide scope for innovative structure designs and can be embossed, cut, creased, folded and glued with ease.	This paper has excellent surface and printing characteristics., it gives wide scope for innovative structure designs and can be embossed, cut, creased, folded and glued with ease.	High stiffness, a smooth surface, excellent printing characteristics and suitable for the packing of aroma- and flavour-sensitive products as well as safety product aspect due to consistent purity for virgin fibre.	The overall content of WLC varies from about 80 to 100% recovered fibre depending on the choice of fibre used in the various layers which help optimizing cost as well as get target expectation of paperboard characteristics.

1.2. The manufacture processes

1.2.1. Raw material and additives

The main raw material used to make paper and paperboard is cellulose fibre sourced from trees and recycled waste. Fibres are mixed with additives to improve performance and control processes and where necessary treated with coatings to further improve performance.

Fibre length is one of the most important properties concerning paper and paperboard performance, and the length and shape of the fibre depend on the source. Deciduous trees (hardwoods) such as aspen, eucalyptus and birch trees grown in temperate climates produce short fibres, whereas coniferous trees spruce, larch, fir, hemlock and pine (softwoods) provide long fibres. Short fibres provide smoothness for printing while long fibres provide strength. Typical ranges of fibre length used in papermaking are:

- Short hardwood fibres: 1–1.5 mm in length
- Long softwood fibres: 3–4 mm in length.

Recycled fibres vary widely depending on the waste raw material source and are often contaminated with printing inks, products and 'contraries' such as plastic, baling wire, wax and adhesive. In general, they are a mixture of hard and softwoods, fibres are shortened at each recycling process and their fibre length depends on the number of times they have been recycled, once virgin fibres have been recycled around seven times, the fibre length is considered too small to use further. These small particulates of colour, text, grease and char spots due to the incompletely deinking process can lead to reduced whiteness and brightness as well as reduced strength (due to the shortening of fibre length) of the finished substrate compared to that manufactured from virgin fibre.

In addition to fibres, which constitutes around 89% of the raw material used for paper and paperboard, there are a number of non-fibrous additives helping to improving either the appearance or performance of the product or the productivity of the process. These comprise:

- mineral pigments used for surface coatings or as fillers (clay, calcium carbonate (chalk) or titanium dioxide) involves the application of one or more layers adhere together and coated on surface paper by an adhesive or binder to control surface appearance, smoothness, gloss, colour (usually whiteness by using fluorescent) and printability. Mineral pigment used for coating and as fillers account for 8% of the raw materials used by the paper industry.
- internal sizing additives (known as 'alum' reacts with rosin and chemically unrelated synthetic resins to produce a modified resin soap deposited onto the fibre surface) help fibre is treated to render water-repellent. Besides, most internal sizing is performed using alkyl ketene dimer (AKD), a waxy substance, alkenyl succinic anhydride (ASA) or other synthetic sizing agents.
- strength additives such as starch used to increase strength by increasing interfibre bonding within the sheet and interply bonding in the case of multi-ply paperboard.
- surface sizing additives, 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 the surface strength which is important during printing and also prepares the surface for mineral pigment coating.
- chemicals used to assist the process of paper manufacture such as 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.

1.2.2. Fibre separation from wood (pulping)

There are two main types of pulping process for the production of virgin fibre and two intermediate methods. These are mechanical (or groundwood) and chemical pulping; and recycled fibre is prepared in a separate process using a hydrapulper are shown below table; thermomechanical (TMP) and chemical thermo-mechanical (CTMP or semi-chemical) process improve the properties or reduce the costs of fibre production.

In the TMP process, lignin can be softened using heat (hot water) prior to or during pulping, or by the action of certain chemicals and render the fibres more supple, resulting in less damage during the mechanical process. Consequently, higher strength and quality pulp compared with the basic mechanical pulping process.

The CTMP process, consisting of some chemical digestion, consumes less time and heat than the chemical process, therefore reducing total costs. The process partially digests the wood mass, removing some of the impurities before mechanically grinding the softened fibres. Mechanical pulp retains the colour of the original wood although CTMP is lighter in colour because more lignin is removed.

1.2.3. Post-pulping treatment of fibres to improve performance

a. Beating and refining (One process)

The beating and refining of fibres are one of the most critical processes in paper manufacture known as the ‘stock preparation" stage. The additives might also be added in this stage to modify fibres' properties. This process bruises/splits the fibres, increasing their flexibility and extending their surface coverage, but reduces fibre length distribution, deterioration the overall paper or paperboard if the process is prolonged. These changes of properties can be effect on:

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

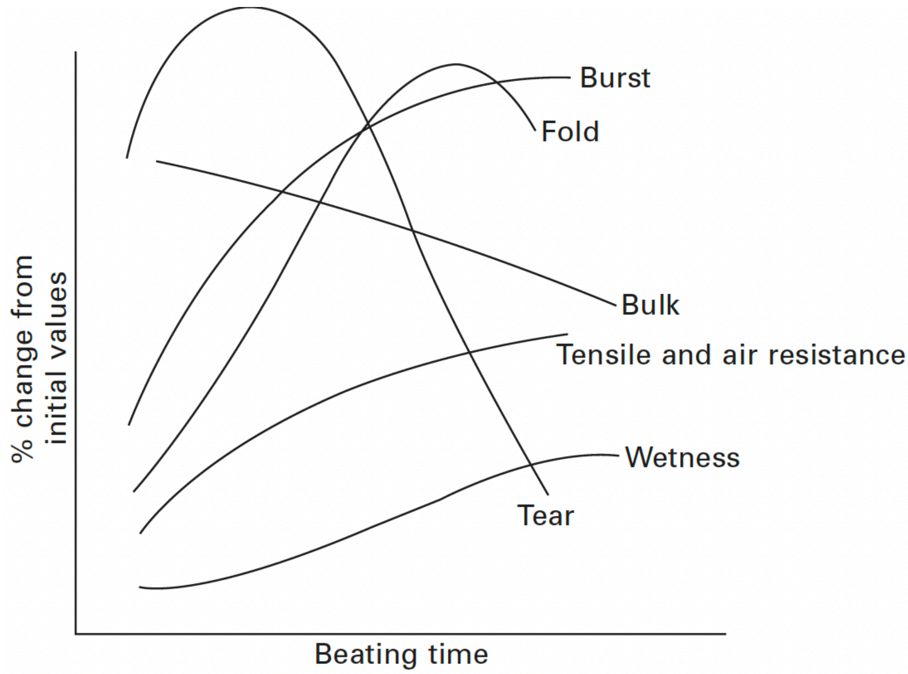


***Figure 2** - These changes of properties’s pulp under beating time*

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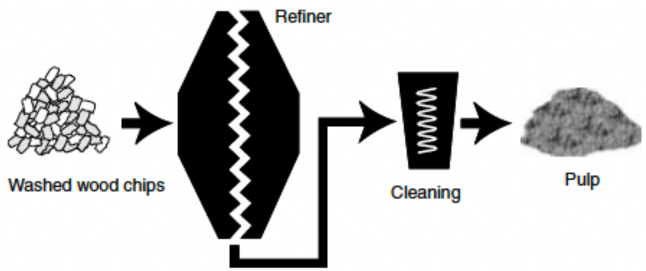
<td>
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Mechanical pulping process in which the wood chips are washed to remove any soil, stones or other contaminants, and mechanically ground. The grinding process was traditionally carried out using grindstones similar to those used for grinding flour, to grind the logs directly. This is known as stone groundwood. Nowadays, ridged metal discs called refiner plates are used to process the wood chips. This process separates the fibres individually but in doing so breaks them into shorter lengths.

Mechanical pulp is used for low grade papers such as newsprint and for blending with chemical and semi-chemical produced pulps to reduce costs.

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Pros: The quickest and least costly method of obtaining virgin fibres. The yield of pulp from wood is very high due to not remove lignin.

Cons: The presence of lignin and other impurities, results in fibres discolour with age, hard and stiff fibres and low density.

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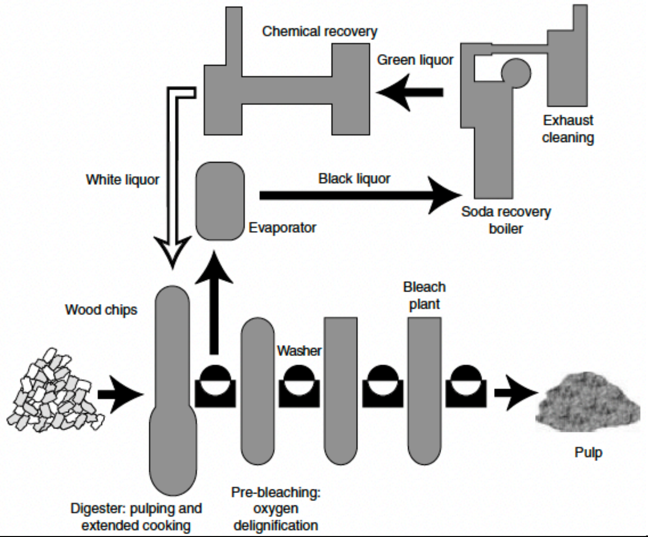
<td>
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Chemical pulping process uses chemicals to separate the fibre by dissolving the non-cellulose and non-fibrous components of the wood. There are two main processes characterized by the names of used chemical types:

- The sulphate, or Kraft, process uses strong alkali, which can be recovered and reused, such as sodium hydroxide and sodium sulfide; it is most widely used today because it can process all the main types of wood
- The other is the acid sulfide process.

If white fibres are required, bleaching is carried out at this stage to get the strongest and whitest substrates.

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 is referred to as 'integrated' mills, manufactured both pulp and paper/paperboard on the same site.

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Pros: Pulp comprises 74% of virgin wood fibre production with the average fibre length is longer than mechanically separated fibre, stronger and more flexible sheet along with toughness, whiteness and purity.

Cons: Lower yield than mechanically separated pulp because it has removed the non-cellulose constituents of the wood and required the consumption of heat energy and chemicals

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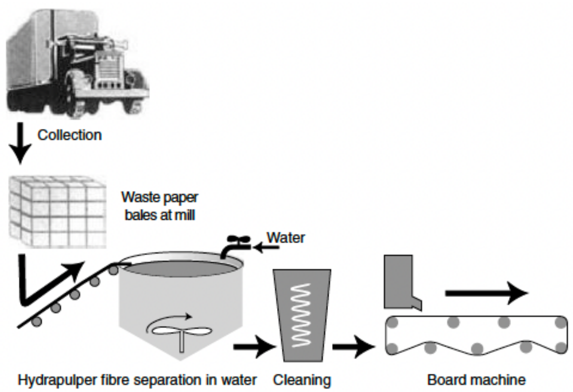
<td>
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Pulp production using a hydrapulper with the large sheets of pulp are often dropped into the water contained in the vessel and dispersed in it to the required concentration – between 0.3 and 3.0% depending on whether paper or paperboard is the intended product. The higher concentrations are used for paperboard. The dispersion of fibre in water, plus the other additives and process aids, is known as the 'furnish'.

Recycled pulp is also produced by using a hydrapulper with less than 90% is recovered due to losing of fibre and being unfit for use. Some recycled paper and paperboard materials need to be supplied at up to 20% greater basis weight to provide the same performance characteristics, compared to some virgin paper and paperboard

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Pros: Much more competitive price for recycled pulp than mixing and virgin pulps. Flexibility in adjusting the properties of paper and paperboard by changing the mixing proportion of fibre types as well as the paper ply structure.

Cons: Recycled paper has the performance and aesthetic less than other papers.

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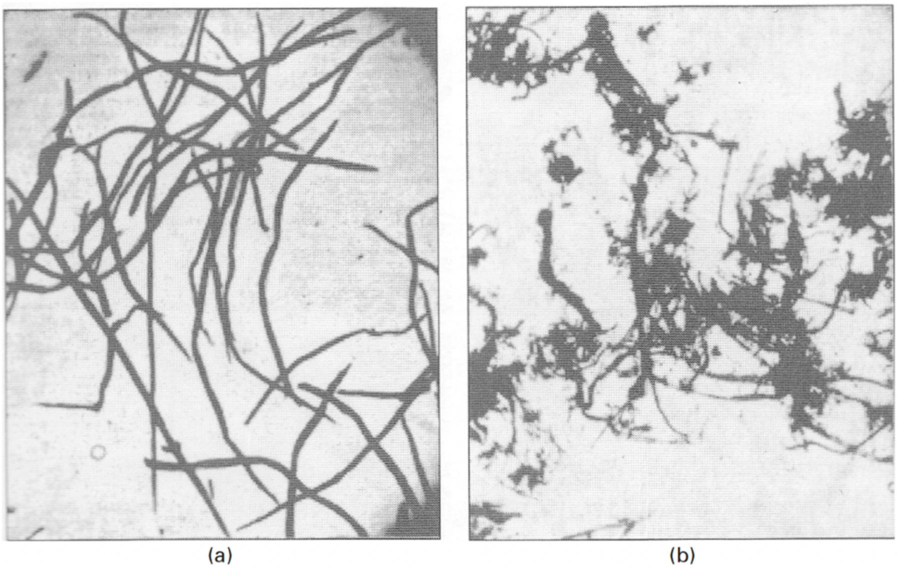
Refining is carried out by passing the pulp suspended in water across rotating surfaces, originally performed in a beater. The below picture shows how fibres before (a) and after (b) beating



A batch process (where considerable beating is required to produce greaseproof and glassine grades of paper) commonly performed by beating method in which the pulp suspension being drawn between moving and stationary 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.

A continuous process required minimal refining, in-line, through a refiner uses a more sophisticated beating process where the fibres are passed through rotating discs (or stationary and moving bars), mounted either conically or on parallel discs.

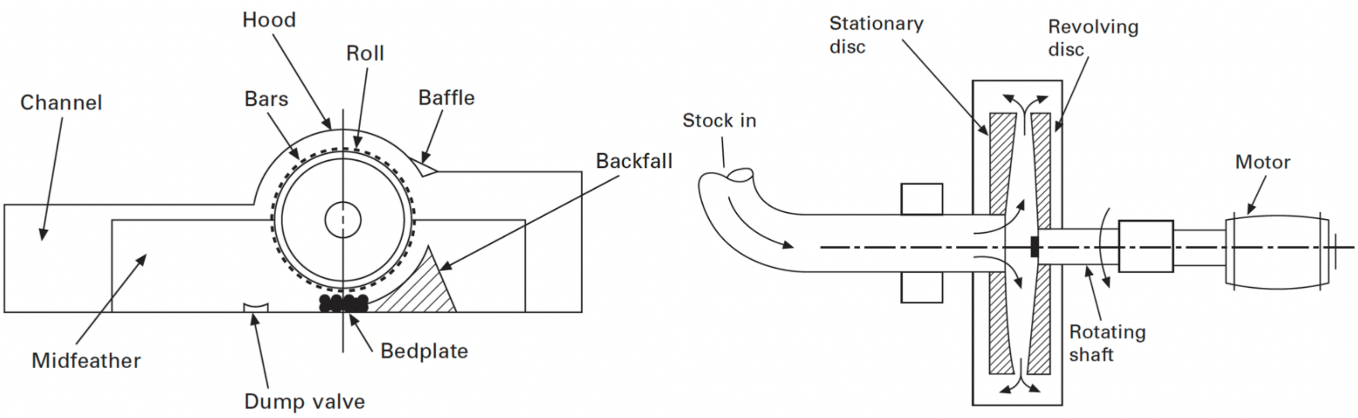


Figure 3 *- The process of beating of fibres by rotary roll (left) or Rotating disc refiner (right)*

b. Bleaching (Whitening)

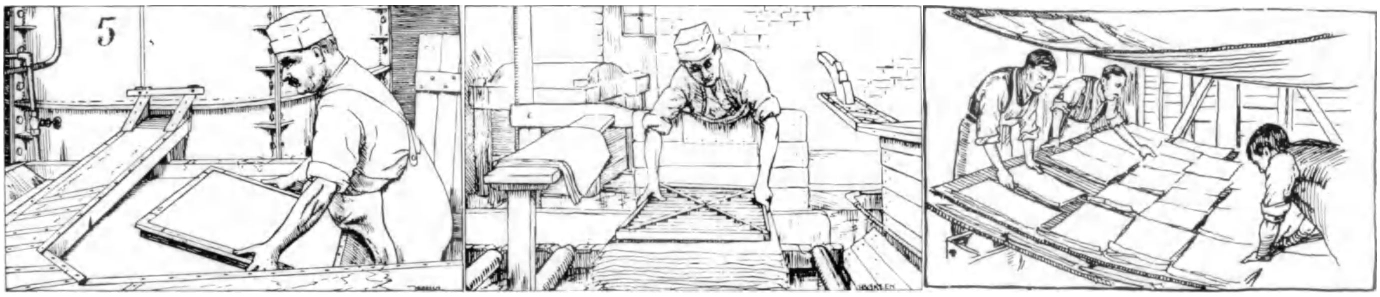
Chemically separated pulp can be whitened or bleached by processes which remove residual lignin and traces of any other wood-based material. Mechanical pulp, even if bleached tends to yellow over time. Bleached pulp has a consistent white colour even though individual cellulose fibres are colourless and translucent. Chemically separated and bleached fibre is pure cellulose because it has particular relevance in effecting sensitive products based on the flavour, odour or aroma of the product packaged. Bleached cellulose fibre has high light stability, i.e. the tendency for fading or yellowing in sunlight is much reduce.

Traditionally bleaching, still used around 25% worldwide, was done using chlorine to dissolve some of the lignin remaining in pulp. Nowadays, the amount of pulp bleached in this way has declined due to the environmental disadvantages and potential safety hazards of using chlorine and replaced by 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.

1.2.4. Manufacture on the paper or paperboard machine

Traditional papermaking was achieved manually via a wooden mould with a finely woven flat wire mesh, dipping into a vat of fibres suspended in water to get an right amount of fibres. Then, water was drained through the wire mesh and left the layer of fibres consolidated. This process was repeated several 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 and continuously removed water by drying in air. Sheets intended for printing would then be tub-sized by immersion in a solution of gelatin, pressed and re-dried in air.

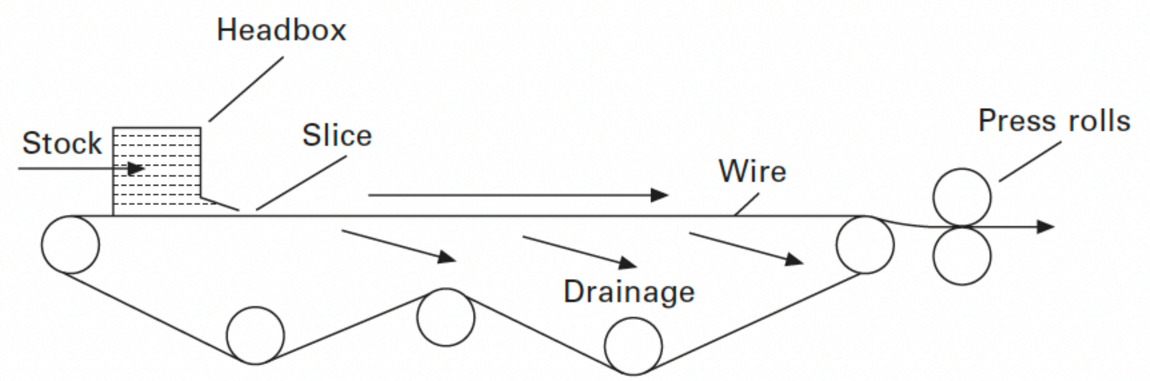


The principles of papermaking today are basically unchanged compared to the past. There are two main types of paper or board mills with three distinct stages:

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

A - The Fourdrinier method

The principles of paper and paperboard manufacture by the Fourdrinier process are described as the below process. A dilution of fibre in water varies from 0.3 to 3% concentration depending on the paper weight of paper or paperboard requirement. Weights may vary from 12 gsm for the lightest tissue paper to 600 gsm for solid bleached paperboard made from chemical pulp. The heavier the paper/paperboard is manufactured, the higher the concentration of fibre suspension in water is.



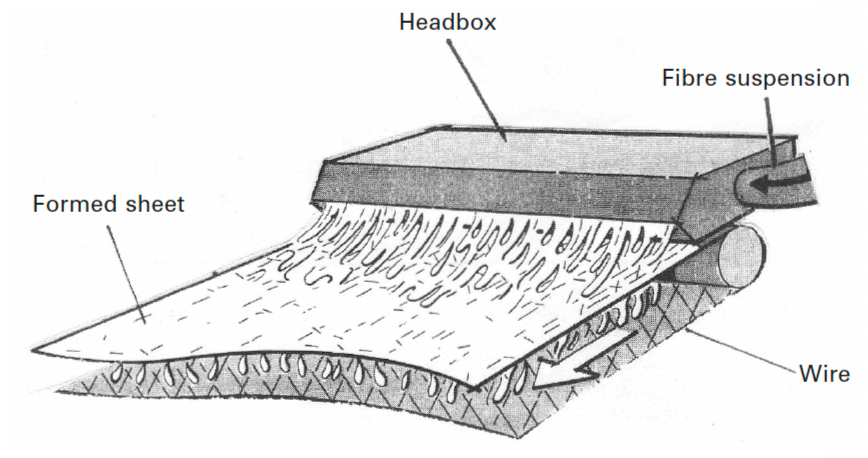
The furnish is held in those tanks holding a specific fibre and additive combination and it is fed into a headbox, which spreads it onto a wire (plastic or metal meshes) via the slice, which controls the flow. The water drains away through the wire, usually assisted by vacuum suction boxes. The movement of the wire means that the fibres align themselves preferentially in the direction of travel, i.e. the machine direction (MD). Also, the wire is often shaken in the cross direction (CD), to redistribute the fibres and create randomly and no obvious fibre alignment.

The first layer of fibre may be the only layer if making paper and will be the underlayer of making multi-layer paperboard. Depending on the final thickness/weight of the paper/paperboard, other layers are added until the required specification is reached.

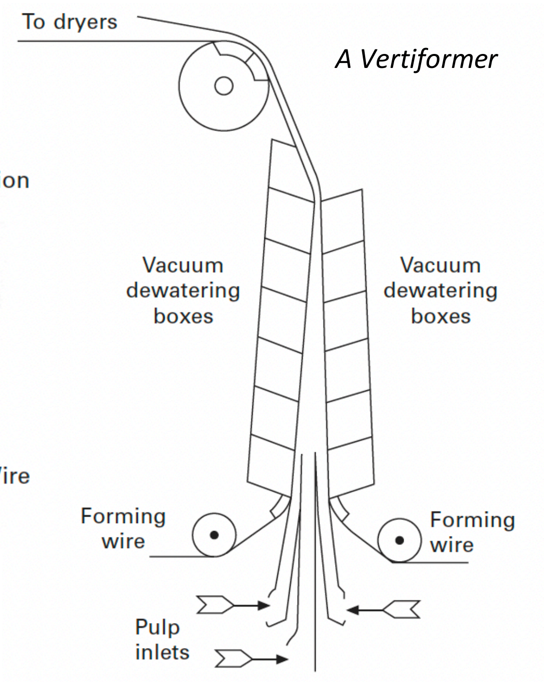
A variation of the Fourdrinier method is the vertical former (‘Vertiformer’) which is a twin wire former. The furnishing is supplied to the space between the formers, picked up by two meshes (wires) on both sides, and water is removed. This has two advantages:

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

The moisture content of the paper or paperboard is still high at this stage at around 60–70%.



Horizontal former



A Vertiformer

B - The cylinder (vat) method

Multi-web or multi-ply, sheet forming can be achieved by using several wires or individual vats containing the furnish required for each layer. A ‘uniflow’ vat is where the pulp suspension flows through the vat in the same direction as the wire mould is being rotated resulting in an even, consistent sheet formation. The opposite flow of fibres known as ‘contraflo’ method allows a greater amount of fibre to be deposited on the cylinder resulting in a thicker and heavier board being produced for the same number of vats used. However, the interply bond strength using contraflo is weaker than with uniflow.

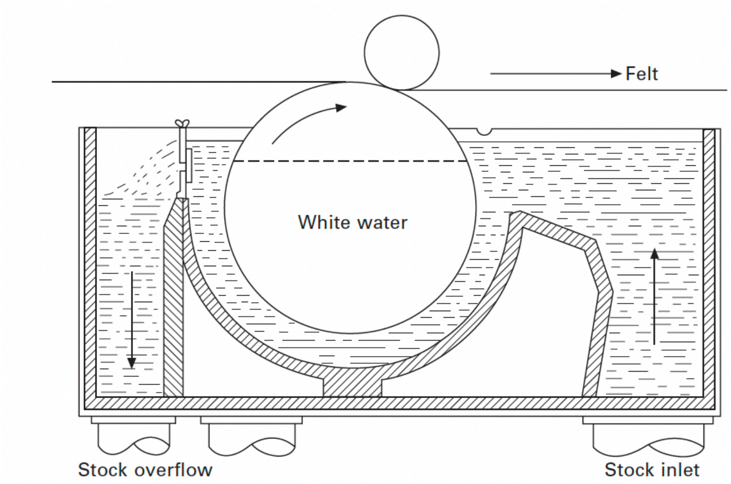


Figure 4 *- A 'uniflo' vat cylinder*

A modification of the wire-forming method is the Inverform process where a second and subsequent headboxes add additional layers of pulp. Different pulp fibres, e.g. chemical, mechanical, and recycled, can be added via the individual vats to build up a multilayer structure. As each layer is added, a top wire contacts the additional layer and drains water upwards as a result of the mechanical design assisted with the 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.

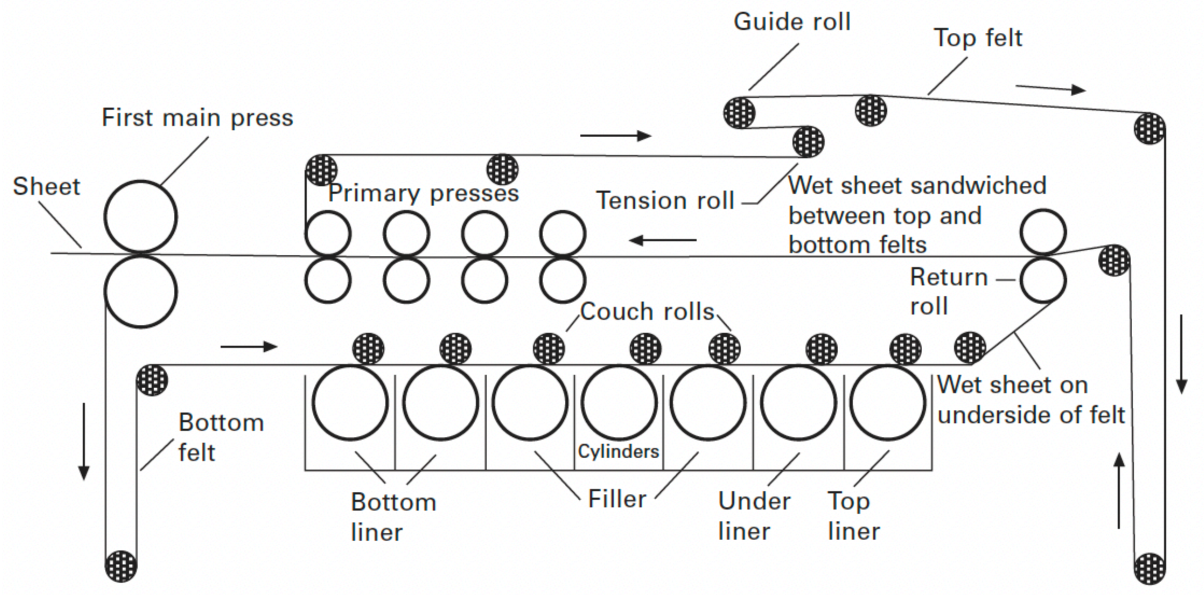
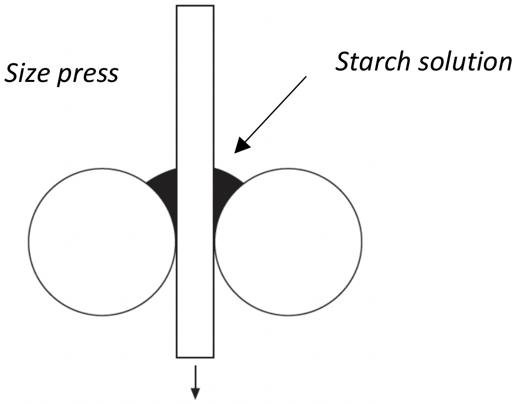


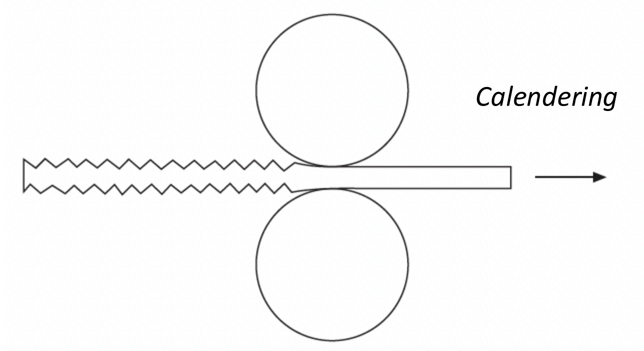
Figure 5 *- Vat paperboard machine.*

C – Finishing process.

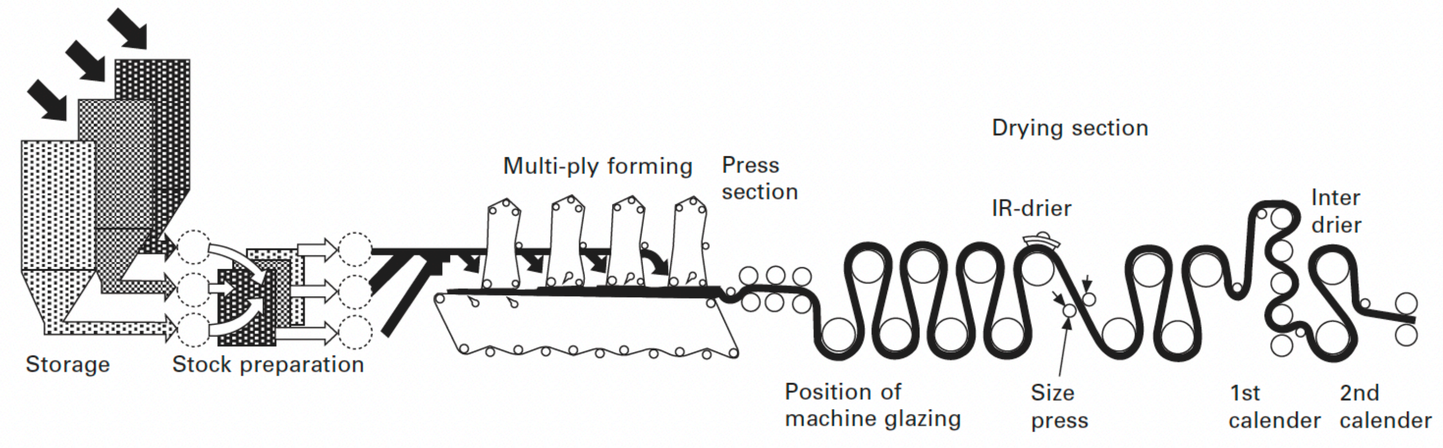
The wet substrate is then sandwiched between felt blankets and passed through the press section where steel rolls remove more water by pressure and vacuum from the fibrous web. The web then passes to the dry end of the machine where more water is removed by evaporation using steam heated steel cylinders producing a typical final solids content of 92–95%. At this stage web can pass over a large polished metal cylinder known as MG (glazed machine) to create a smooth surface finish and reduce its thickness and stiffness.

Immediately after the drying section, surface sizing can be carried out on one or both sides of the sheet to prevent fibres shedding from uncoated surfaces and improves surface strength and smoothness, hence in respect of printability and varnishing.





Calendering or ironing process give a uniform thickness and smoothness to the paper or paperboard, takes place once the substrate has been sized. The dry substrate is passed between cylinders (often steel rolls (hard) or composite material(soft) or a combination of both types) which can be cold or heated, to provide very smooth glossy finishes. Water may be applied to assist and enhance the smoothing effect. Some papers are produced by an off-machine known as 'super calendering' having up to 14 rolls, to produce a translucent paper.



❖ ***Figure 6*** *- A Fourdrinier papermaking process using multi-formers*

If required the web is now coated with a white mineral pigment base (clay or chalk) to give a hard smooth surface suitable for high-quality printing. There are many ways to add the coating and, depending on the colour of the web (brown, grey or white), between one and three separate coats are applied. The amount of coating is also governed by the final smoothness required referring to the initial whiteness and smoothness of the web.

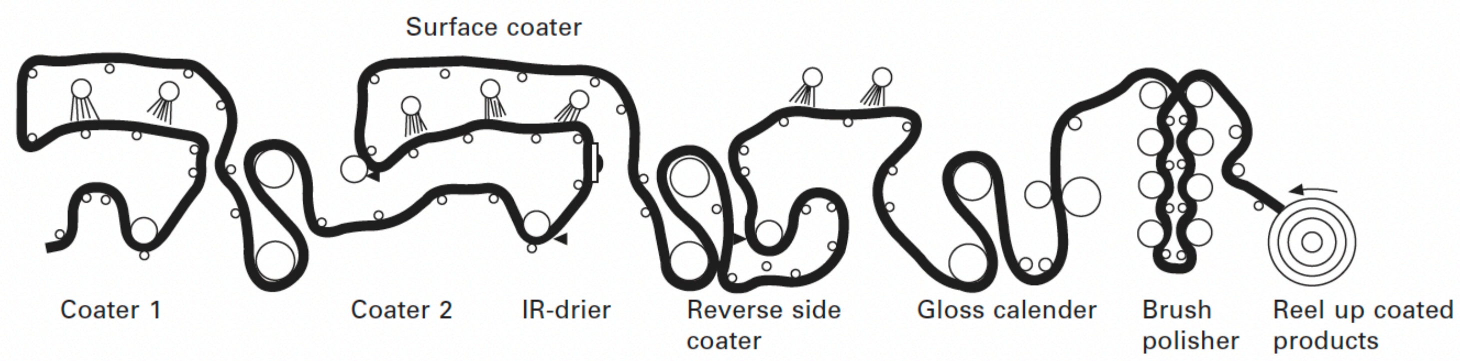


Figure 7 *- A typical online coating process applies after Fourdrinier papermaking process*

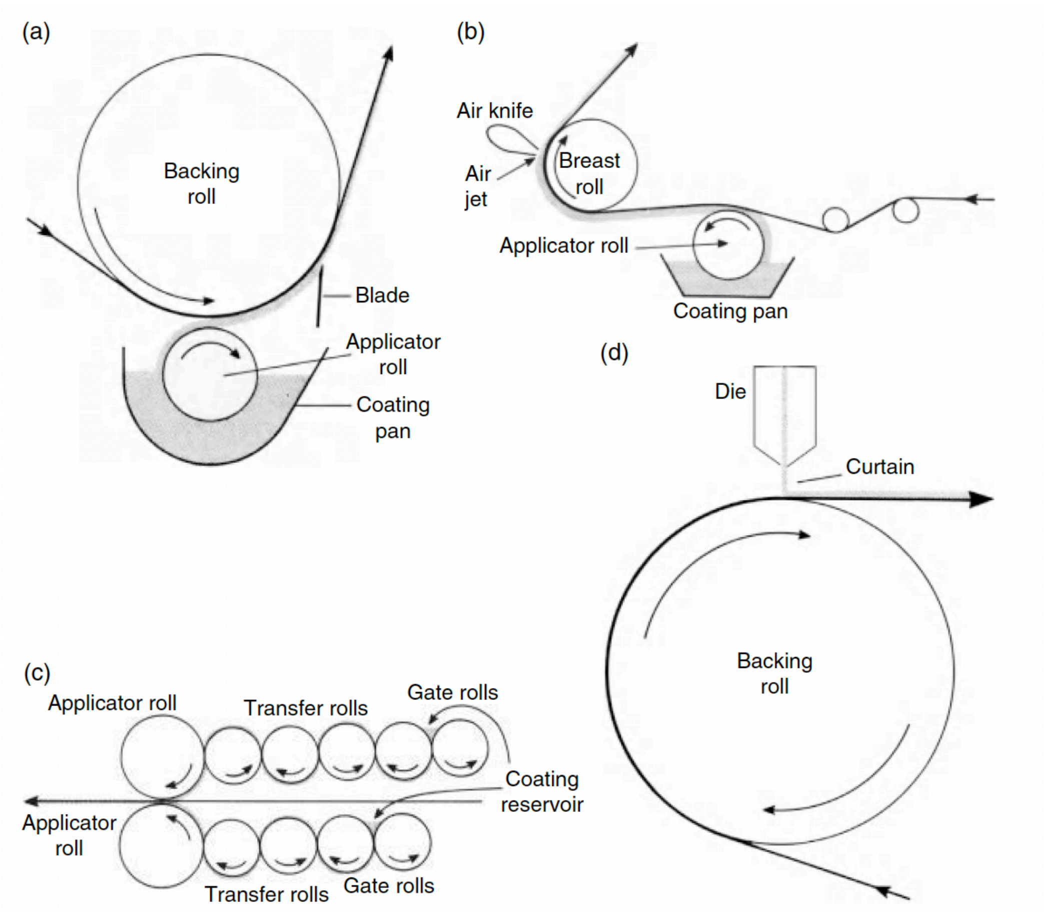


Figure 8 *- (a) Blade coating, (b) air knife coating, (c) roll coating and (d) curtain coating.*

The quality of the coated surface is influenced by the mechanism by which the coating is applied. The double-blade process is the most popular technique giving superior results to those using an air knife. Currently, curtain coating has become more popular and has some advantages over the other methods such as there is no physical contact between the coater and paper web; this reduces the occurrence of web breaks, so increasing productivity. Other coatings such as wax or synthetic polymers can be applied as an emulsion or molten liquid, either on-line or off-line the paper /paperboard-making machine. Where both sides are coated contemporarily, a process is known as 'cascade coating' and uses the 'curtain coating' method.

Binders are used to achieve good adhesion between the coating and the base web, and between the mineral particles within the coating. Optical brightening agents may also be added to the clay coatings, especially for cartons for retail display.

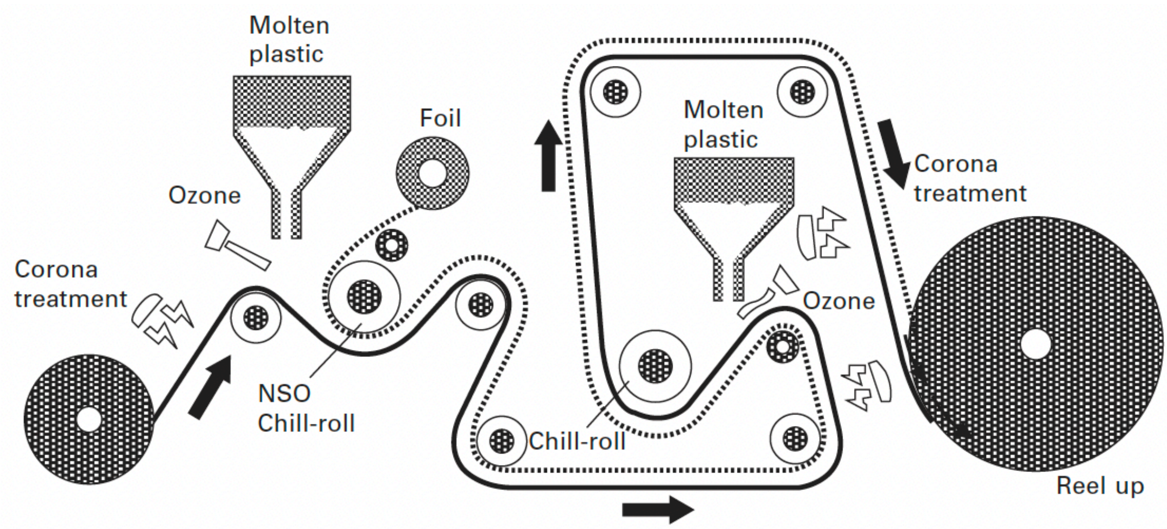


Figure 9 *- An instance of an extrusion coating and lamination. The details will be discussed in chapter II.*

An alternative coating for wax or synthetic polymers is polymer film which is either directly laminated on the surface of paper and paperboard via an adhesion process or an extrusion coating. The correct selection of polymer film can add to the benefits of paper and paperboard, providing a barrier to moisture and gas (especially in combination with aluminium foil), grease resistance, water resistance, heat seal-ability, high gloss finish, and, using reverse print techniques, protection of the decorated surface.

A disadvantage of wax, synthetic polymers and plastic film coating when applied on paper/paperboard hinders recyclability as they have to be removed at or before the hydra pulper. So that the water-based functional coating has been developed to provide similar protection without leaving any undesirable residues.

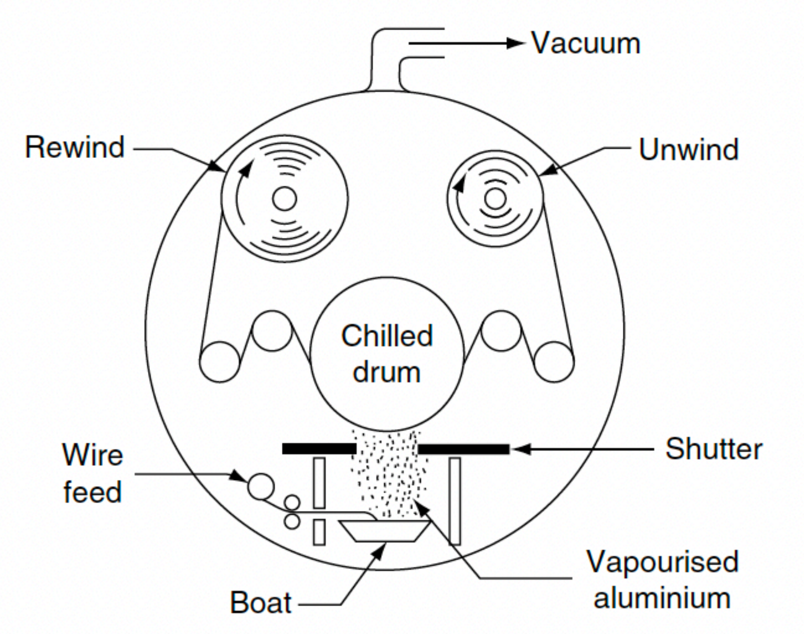


Figure 10 *– The metallisation process.*

Metallisation process whereby aluminium is vaporised in a vacuum and deposited to form a thin layer (3-4 mm) on the surface of the substrate. This process has been applied to both paper and film but metalising a metal layer on paper is more difficult than film because the paper has a less smooth surface and thicker than film, and changeable moisture content. So, the paper surface can be clay coated and pre-lacquered to make the surface smoother and improve the metallised appearance. Another metalisation process on paper is the pre-metalising layer on PP film then transfer to paper with the help of an adhesive. In this way, the plastic film (PP) can be reused. Metallised polyester film (PET or PETE) has been laminated to paper and paperboard as an aluminium foil replacement or the metallisation process for paper due to on cost.

1.2.5. Control of quality of paper and paperboard

Moisture content, thickness, basis weight and stiffness are constantly monitored in the mill laboratory and adjustments made to the machine to ensure the parameters stay within the limits of the specification. It is important to recognise that paper and paperboard substrates have different properties when measured in the cross and machine direction:

- the wire method has a MD:CD ratio in the region of 2:1
- the vat method has a MD:CD ratio in the region of 4:1.

The relationship between the two directions is a complicated one. It is not just the MD stiffness that needs to be taken into consideration but the CD as well. Most tests are carried out under controlled conditions of temperature and humidity to ensure they are repeatable and completely comparable. The international standard for test conditions is 23°C and 50% RH. The table below shows various tests for paper and paperboard. The details and explanation of *performance properties* are shown in the appendix.

Tests for surface appearance		*Tests to control performance properties*	
Test	**Test method**	**Test**	**Test method**
Surface strength	ISO 3783-2006	Thickness	ISO 534-2005
Surface tension	ISO 8296	Basis weight	ISO 536-1995
Whiteness	ISO 11476-2000	Water absorption (Cobb test)	ISO 535-1991
Brightness	ISO 2470.2-2008	Moisture content	ISO 287-1985
Opacity	ISO 2471-2008	Bending resistance/ Stiffness	ISO 2493-1992 ISO 5628
Surface roughness	ISO 8791.3-2005	Short span compression strength	ISO 9895-2008
Porosity	ISO 5636	Tensile strength (dry)	ISO 1994.2-2008
Gloss	ISO 8254.3-2004	Burst strength	ISO 2758-2003
Rub resistance	ISO 8254.3-2004	TEA (Tensile energy absorption)	ISO 1294
Surface pH	Tappi T529 om 09	Elmendorf Tear resistance	ISO 1974-1990
Ink absorption	Tappi T553	Interply bond strength (z direction tensile strength)	ISO 15754- 2009
		Coefficient of friction	ISO 8295-1995
		Taint and odour Robinson sensory test	EN1230.2-2001

Depending on customer requirement, large reels ex-machine is 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.

II. Paper and Paperboard Packaging

Paper- and paperboard-based products can be made in a wide range of grammages and thicknesses, the choice of fibre, the treatment and additives used at the stock- preparation stage. The most common papers used in packaging and typical end uses are:

- Kraft*: bags, sacks, folding cartons, corrugated liners*
- Sulphite *(70-100 gsm): bags, sacks, folding cartons, dual ovenable trays, liquid packaging, labels, leaflets, corrugated liners*
- CTMP*: corrugated fluting medium, liquid packaging containers*
- Test liners (mixture of virgin and recycled fibres): *corrugated liners*
- Recycled Kraft *(90-110 gsm): spiral wound containers*
- Greaseproof (*30-70 gsm*), glassine (*30-80 gsm*) and parchment (*30-230 gsm*): *wrappers and bags with grease resistance is important*
- Tissue (*12-30 gsm*): *tea bags, industrial packaging, fine jewellery, textiles.*
- SBB, SUB, FBB, WLC (*wide range of gsm*): *folding cartion, multipack or tray, rigid boxes, etc.*

These main packaging formats of used paper can be clasified following paper grammage as below:

Paper grammage < 250 gsm	Paper grammage > 250 gsm
- Corrugated packaging *(discuss in section III.)* - Sacks - Bags - Spiral, linear and convolute wound containers - Liquid packaging cartons. (*Others can below 300 gsm*) - Paper labels (*discuss in label packaging article.)*	- Folding cartons, multipacks and trays - Rigid boxes - Pressed paperboard trays - Blister cards and Euro slot multipacks.

2.1. Paper based packaging (<250 gsm)

2.1.1. Paper-based flexible packaging

Flexible packaging based on paper uses composite structures in which the properties of the paper are combined with those of other materials, such as plastics, aluminium foil, wax and other materials utilizing coating, lamination and impregnation. In this case, paper material plays an important role in providing barrier property, good rigidity/stiffness and good printing surface (depending on printing demand) and good deadfold.

Table 3.1 Barrier requirements for various types of food product

	Moisture	Grease	Oxygen	Odours	Mould	Flavour	Aroma	Light
Biscuits	×	×	×	×				
Yellow fats	×	×	×					×
Cereals	×		×			×	×	
Chocolate		×		×		×		×
Coffee	×	×	×	×		×	×	×
Baked goods	×	×				×		
Dried foods	×		×					×
Dry pet food	×		×			×	×	×
Soap					×		×	
Tobacco	×			×		×	×	
Detergent powders	×	×					×	

Specification	Application
Paper/PE	Flour bags Sugar bags Detergent powder bags
Paper/PVdC/PE	Oxygen and grease sensitive bag-in-box products, e.g. stuffing mix, gravy powder
Paper/cold seal	Ice cream bars Chocolate bars Sticking plaster wraps
Paper/grid heat-seal lacquer	Medical applications requiring sterilisation, e.g. needles, gowns, bandages
Paper/PE/aluminium foil/PE	Dehydrated soup, sauce and dessert powder sachets Instant coffee sachets Biscuits
Paper/metallised polyester/PE	Salted snacks, confectionery bars
Metallised paper	Cigarette liners, beer labels
Aluminium foil/paper	Yellow fat wraps, e.g. butter, margarine
Greaseproof paper	Yellow fat wraps

Paper-based FP is usually supplied on rolls for forming, filling and sealing by the end-user/packer or some pre-made formats such customer's requirement based on packaging machinery.

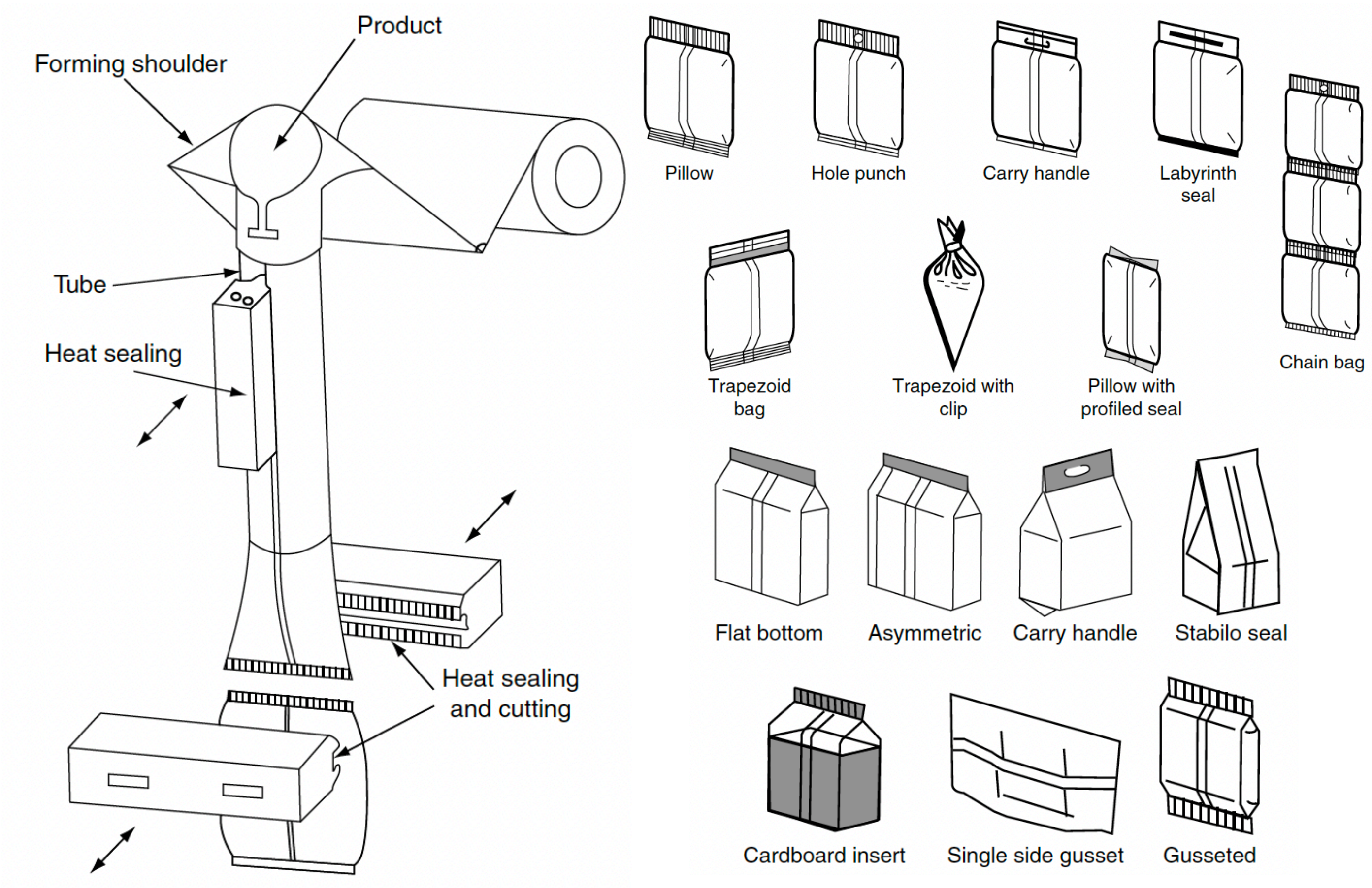


Figure 11 *- Range of typical pillow-type packs, gusseted/block bottom bags produced on vertical form, fill, seal machines.*

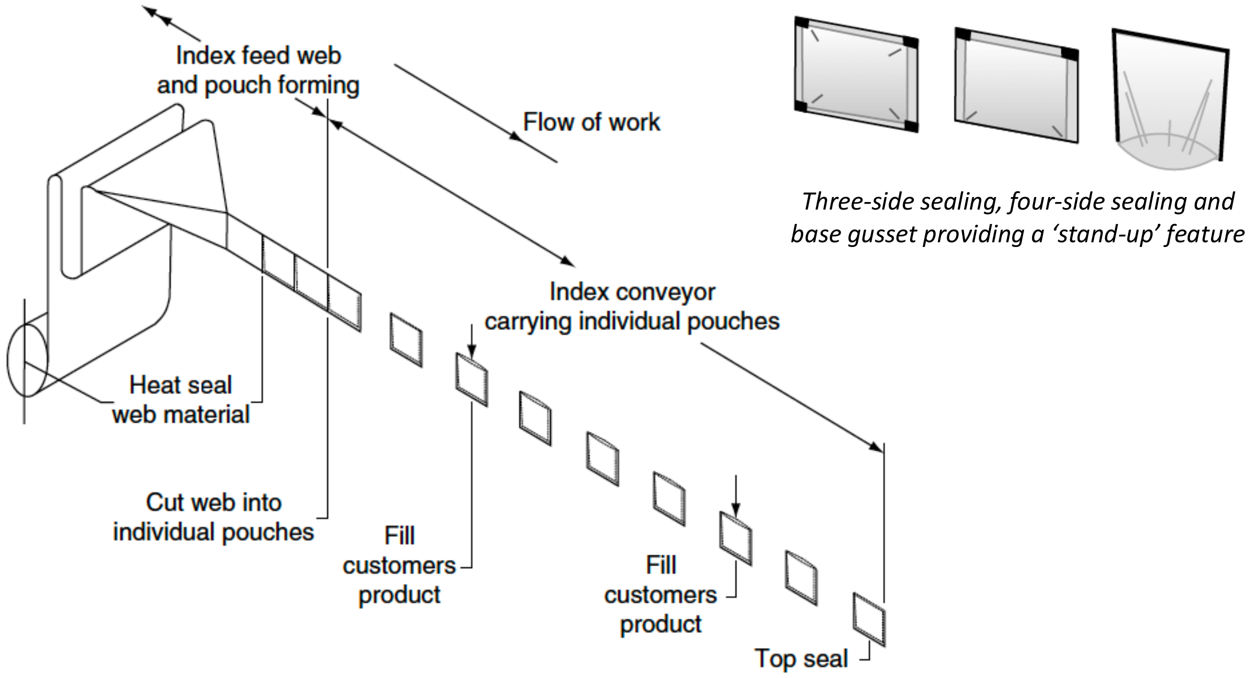


Figure 12 *- Horizontal pouch/sachet form, fill, seal machine for dry mixes (soups, sauces, etc.), pastes and liquid products*

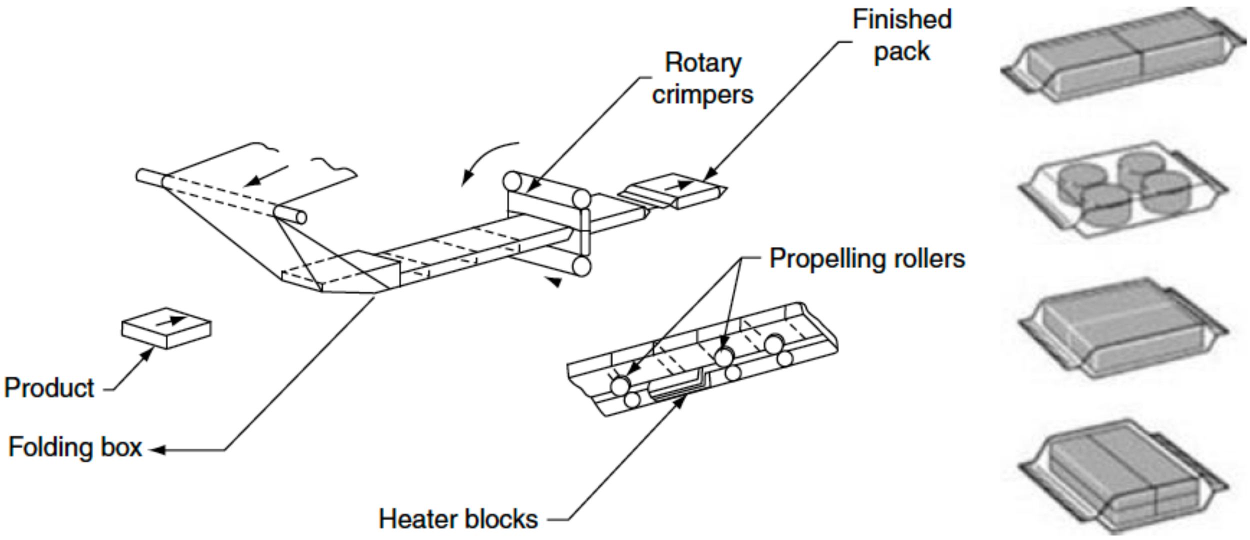


Figure 13 *- Horizontal form, fill, seal-type machine and pack types*

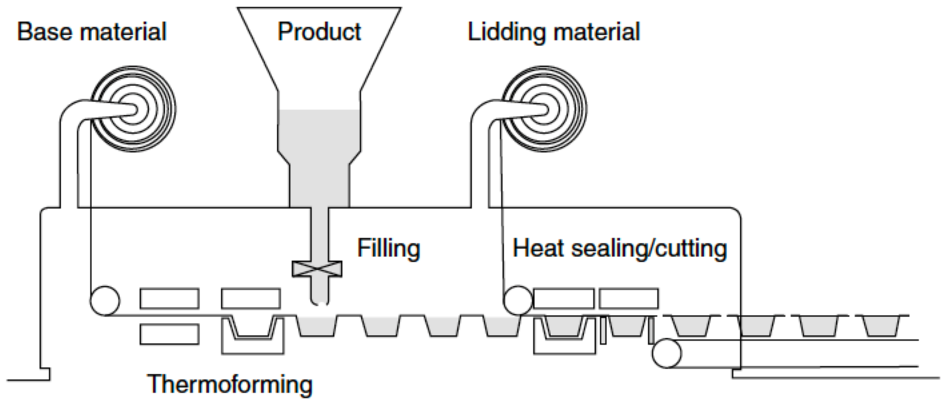


Figure 14 *- In-line thermoforming and lidding.*

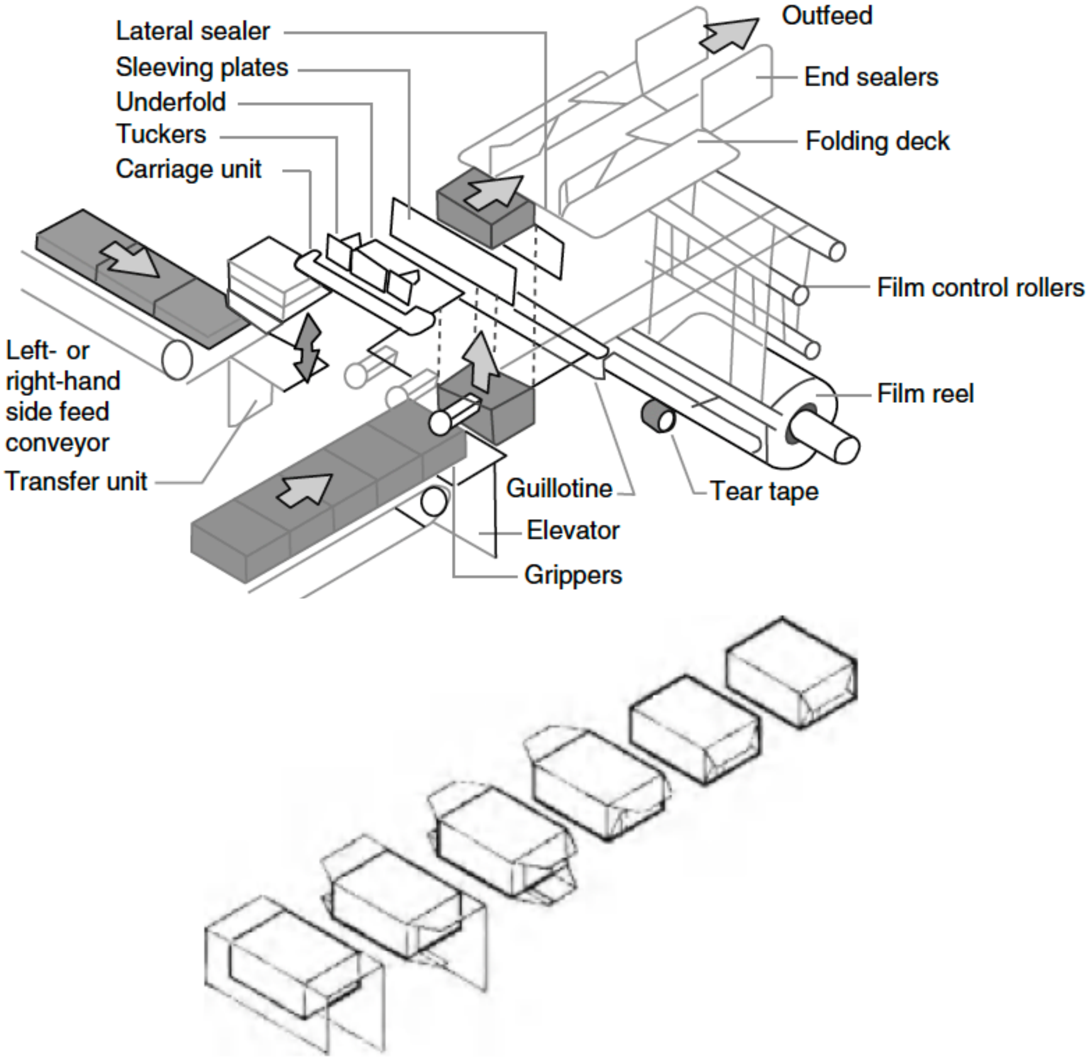
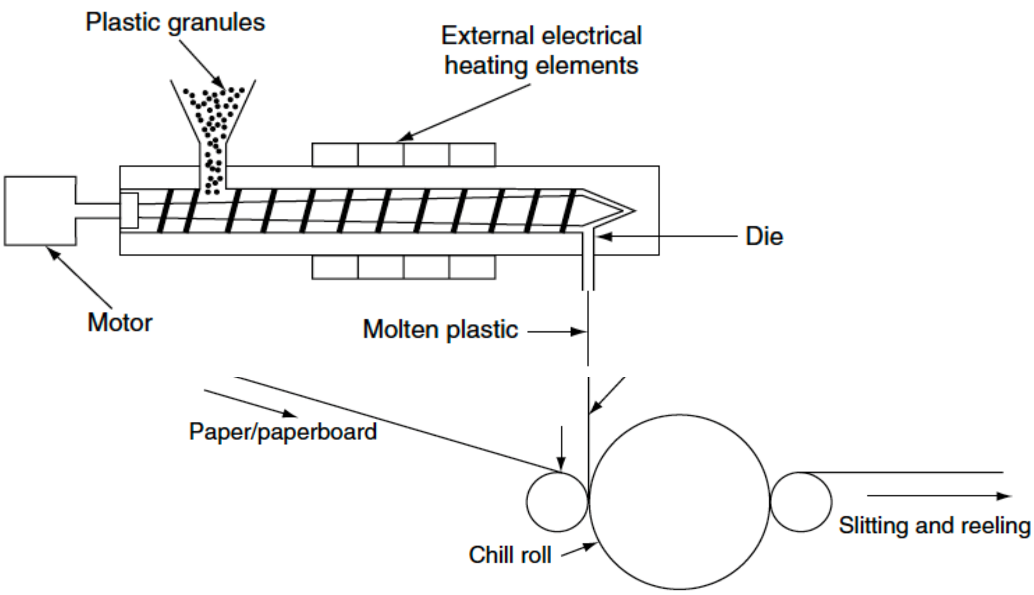


Figure 6 - Overwrapping envelope end fold folding sequence on overwwrapping machine

A – Printing and varnishing for paper-based flexible packaging.

- ❖ **Printing**: The main processes used are flexography and gravure for paper-based flexible packaging, offset litho or digital prinitng sometimes can be apply.



- ❖ **Varnishing:** To protect printed images if the artwork is printed reverse side, also gives a high gloss, rub and product-resistance surfaces together with high heat resistance in the subsequent heat-sealing areas. Varnishes can be solvent-based or water-based coatings which are applied by anilox roll and evaporated by heat. Others are 100% solids coating cured by UV, metallising on paper but not popular, or including wax, hot melt and PE extrusion such as the above diagram.

B – Paper-based flexible packaging production or lamination.

Paper can also be laminated on a pre-printed film or the laminating process in which the functional usage of paper is enhanced with the addition of one or more additional layers, or webs, of material using an adhesive to achieve the bonding of the materials. The various laminating processes include:

- ❖ **Lamination with water-based adhesives (*Wet-bond*):** Water-based starch and polyvinyl acetate (PVA) adhesives are used to laminate paper with aluminium foil. Casein and sodium silicate can also be used as adhesives.
  The adhesive is applied to one of the surfaces and the other surface is combined with it by nip pressure between two rolls. Water is absorbed by the paper substrate leaving the active part of the adhesive in a tacky state on the surface. The combined material then passes through a heated tunnel which dries the adhesive

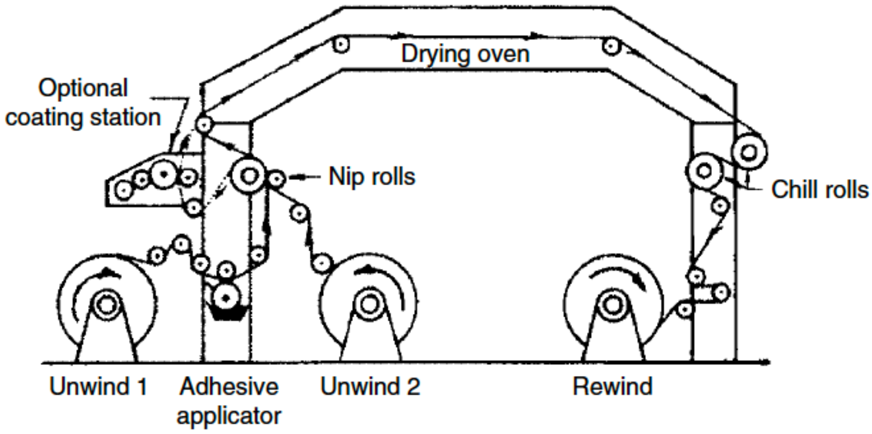


***Figure 15** – Wet-bond lamination*

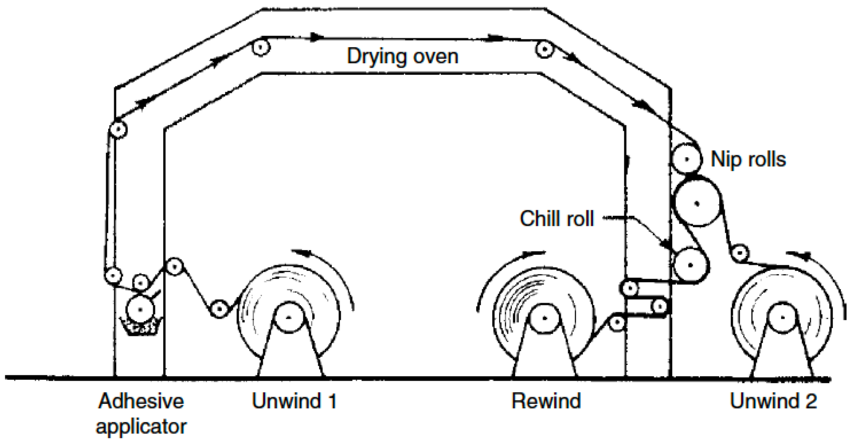


***Figure 16** – Dry-bond lamination*

- ❖ **Dry bonding:** There are two types of dry bonding adhesive, including
  - ***A solvent-based adhesive*** is applied to one substrate and passed through an oven to remove the solvent, finally it is combined with the other substrate between two rolls with nip pressure. This type is usually bonded for two plastic films or one plastic film with one aluminium foil, not usual for laminating paper**.**

- ***Alternatively, the adhesive may be a two-component 100% solids system*** *which is activated by heat under nip pressure. This one is suitable for laminating other materials, film or paper together.*

❖ **Extrusion lamination:** Extrusion lamination is often used to laminate paper or paperboard to other materials via a melten plastic such as PE, PE, EVOH, etc. (See figure 9 & 17).

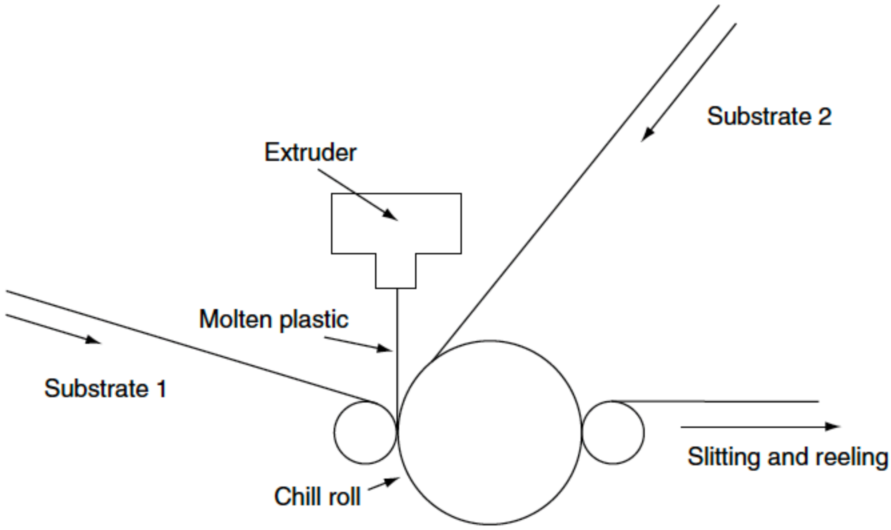


Figure 17*- Extrusion lamination process*

❖ **Lamination with wax:** Wax is used as an adhesive with barrier properties to water, water vapour and gases and odours. For example, Aluminum foil/Wax/Greaseproof paper – the aluminum foil can be printed and embossed for use as a butter wrap.

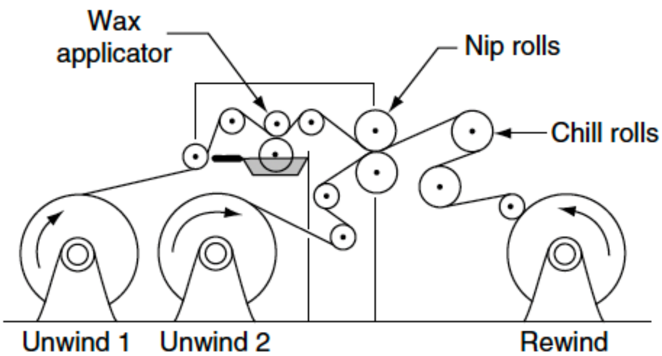


Figure 18*- Wax lamination process.*

2.1.2. Paperboard-based liquid packaging

Early 1900s, John Van Wormer has invented "paper bottle", and he called Pure-Pak®. It was a folded carton plank, which would be supplied flat to dairies for the packaging of milk. This pattern offered several important advantages and still apply today – those of saving in delivery, storage and weight compared with glass bottles.

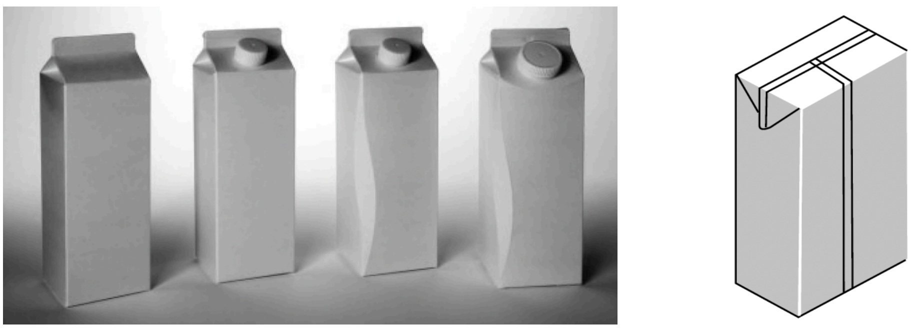
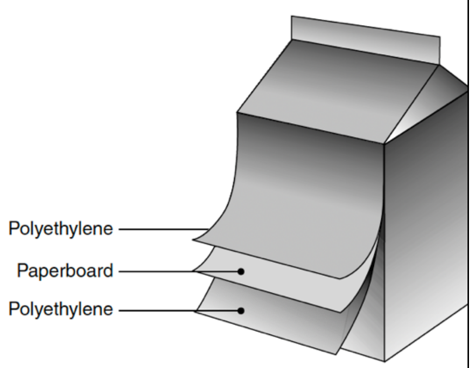


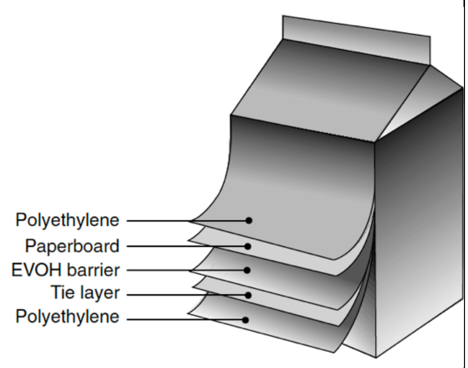
Figure 19 - *(Left to right) Pure-Pak® carton, Pure-Pak® with cap, Pure-Pak® curve, Pure-Pak Diamond® curve. (Elopak) and Tetra Brik® (Tetra Pak Group.)*

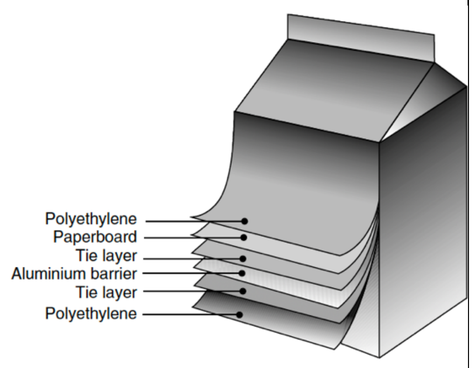
The next generation Tetra Pak was registered in 1950 and become an independent company. At this stage, the technological structure of paper bottle changed by adding other materials such as aluminum, plastic film to provide a higher barrier and protect, sealing and filling easier, etc.

A – Packaging Materials Structure

- ❖ *Paperboard*: provides strength, structure, a hygienic appearance and a good printing surface for liquid packaging cartons. The basic construction is multi-ply paperboard (210–250 gsm) made from virgin fibres to ensure a high standard of odour and taint neutrality. The outer layer is always made from bleached, i.e. white, chemical pulp, and may sometimes be coated with white pigment to give the best print reproduction. The other layers may comprise either bleached or unbleached, i.e. brown, chemical pulp, pulp (CTMP) which its excellent strength and/or whiteness.
- ❖ *Barriers and heat-sealing layers:*
  - A compatible heat-sealing polymer on both the face, top or print side, and the reverse side are usually provided by extrusion coatings of low-density polyethylene (LDPE). PE provide a liquid tightness and humidity protection. PEs with other compatible polymer such as ethylene vinyl acetate (EVA) to improve head sealability.
  - Ethylene vinyl alcohol (EVOH) and polyamide (PA) are good oxygen barriers, flavour protection and oil/fat resistance while PE provide a good barrier to moisture vapour.
  - Aluminium foil is a well-established high-barrier material, which provides a barrier to light, oxygen and moisture vapour, an excellent protection to flavours and has oil/fat resistance. It also provides a metallic finish when laminated to the outside (top side) of the paperboard.
  - Ionomer (Surlyn™) is a moisture vapour barrier like PE and, additionally, has oil/fat resistance, very good hot-tack and heat-sealing properties and is used as a tie layer. It can be extruded onto aluminium foil (process aid) at lower temperature than PE and thereby avoid potential odour from PE extruded at the temperatures necessary to achieve good adhesion.
  - Metallised polyester (PET or PETE) or other metallised films such as polypropylene (PP) and PA, can be laminated to paperboard and is used in bag-in-box laminates. It provides a good barrier to oxygen and moisture vapour replacing for PE and Aluminum layer.







Two-side polyethylene-lined paperboard (Original structure)	Two-side polyethylene-lined paperboard incorporating ethylene vinyl alcohol (EVOH)	Two-side polyethylene-lined paperboard incorporating aluminium foil.

B – Printing and Converting, Aseptic Processing

C – Several Carton designs based on Paperboard-based liquid packaging

2.2. Paper based packaging (>250 gsm)

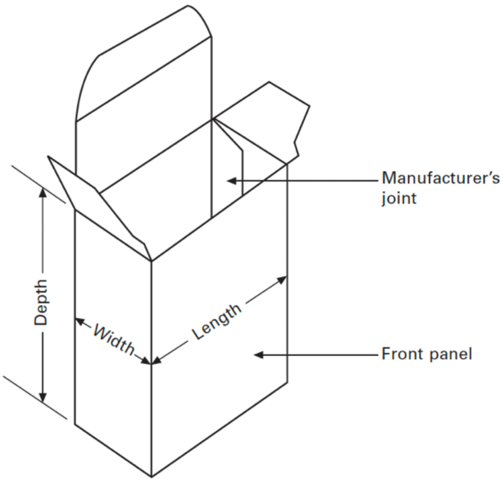
- Folding cartons, multipacks and trays (non-corrugated)
- Rigid boxes
- Pressed paperboard trays
- Blister cards and Euroslot multipacks.

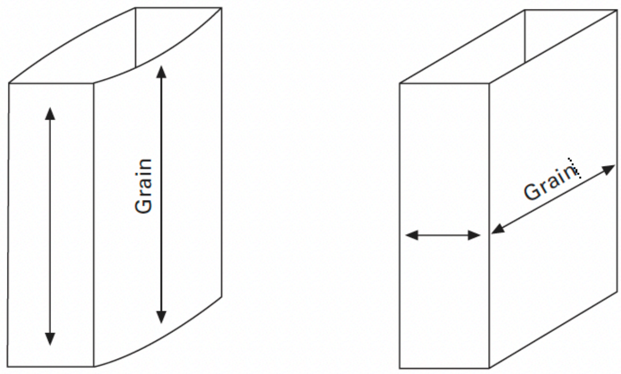
2.2.1 Rigid box and folding carton/ Solid board packaging

Cartons can be defined generally as small to medium sized containers made from paperboard or in some instances paper (< 250 gsm) or plastic (toothpaste and some cosmetics cartons)

All paperboard grades can also be treated with fluorocarbons to give grease resistance (declining due to fears of taint) or coated/laminated with wax (reduced the use of wax as it hinders recycling), plastic films, water-based barrier coatings and aluminium foil to provide gas, moisture, grease, water barrier and heat sealabilty, depending on the combination used.

a. Carton (Box) styles

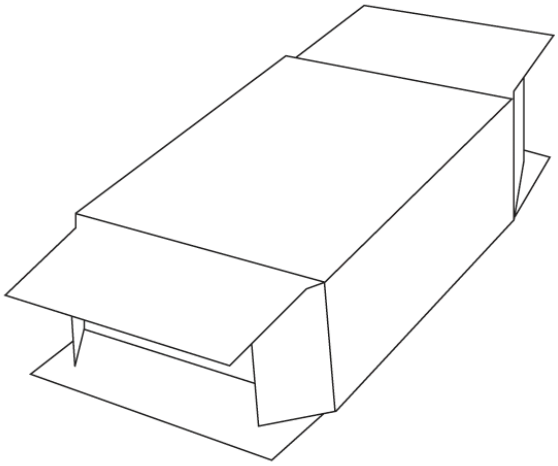




The grain direction of the fibres in the board should always be at a 90° angle to the major creases. This is very important for consistent crease performance and minimal bowing of the carton.

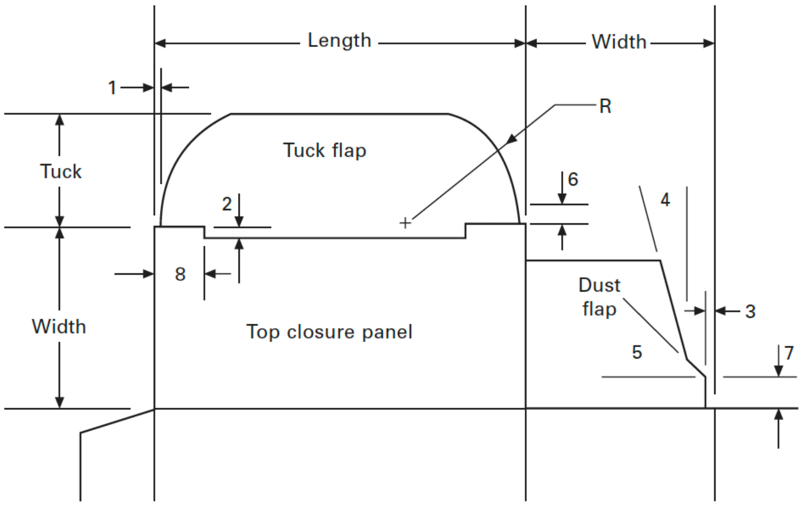
b. Some common carton styles are:

❖ ***End load cartons:*** are designed to be filled horizontally. They consist of four panels, front, rear, left side and right-side panels, glued at the side seam (known as the glue flap). The top and bottom flaps can be glued with hot melt or water-based adhesive, or a tuck flap can be incorporated in the design for mechanically closing and opening.



End load carton use hot-melt or water-based adhesive to close flap.

A cut is often made at the ends of the flap crease which creates a mechanical lock with the minor flaps helping to prevent the carton opening in transit.



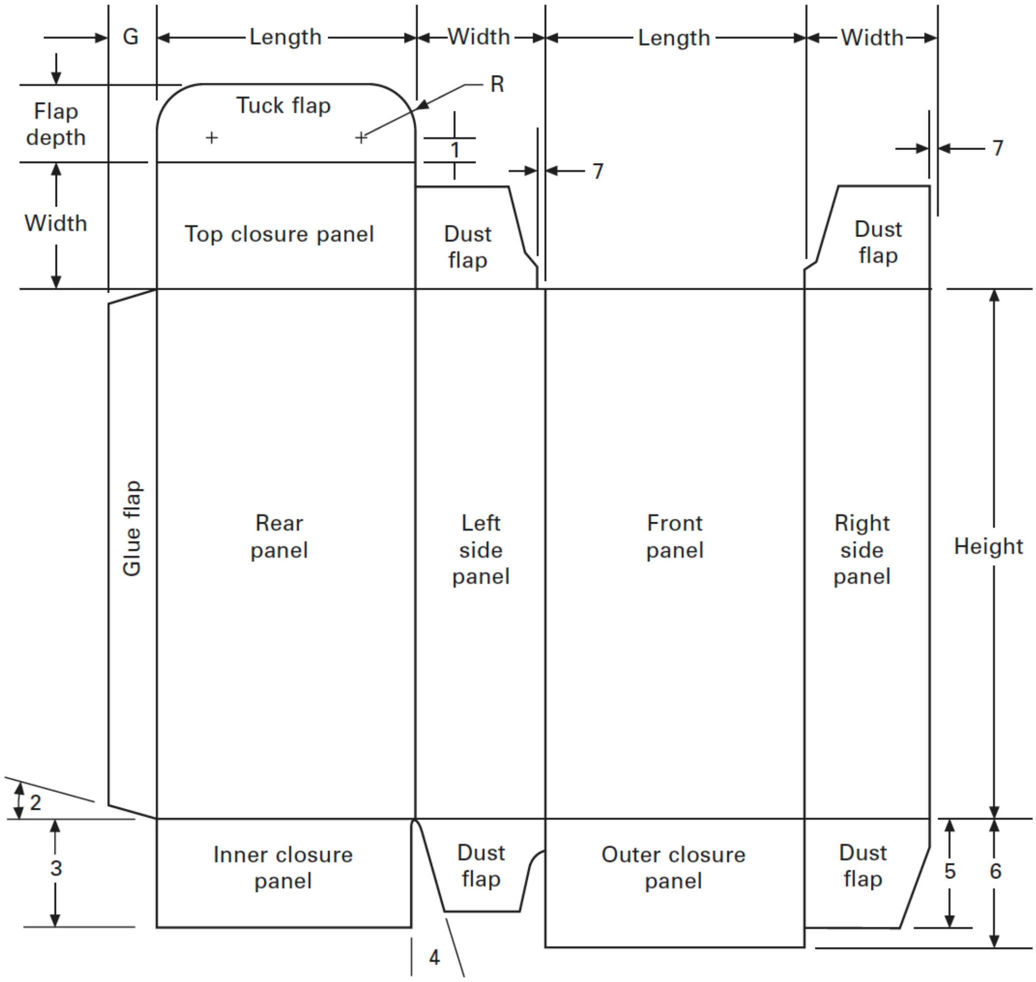


Figure 20. *End loads carton design and diagram showing dimensions*

❖ ***Top load cartons:*** The top load carton is supplied to the packer/filler as a flat blank. It is formed through a die and the side panels are mechanically locked or glued, normally by hot melt adhesive; the product is then filled through the large top aperture and the lid is closed.

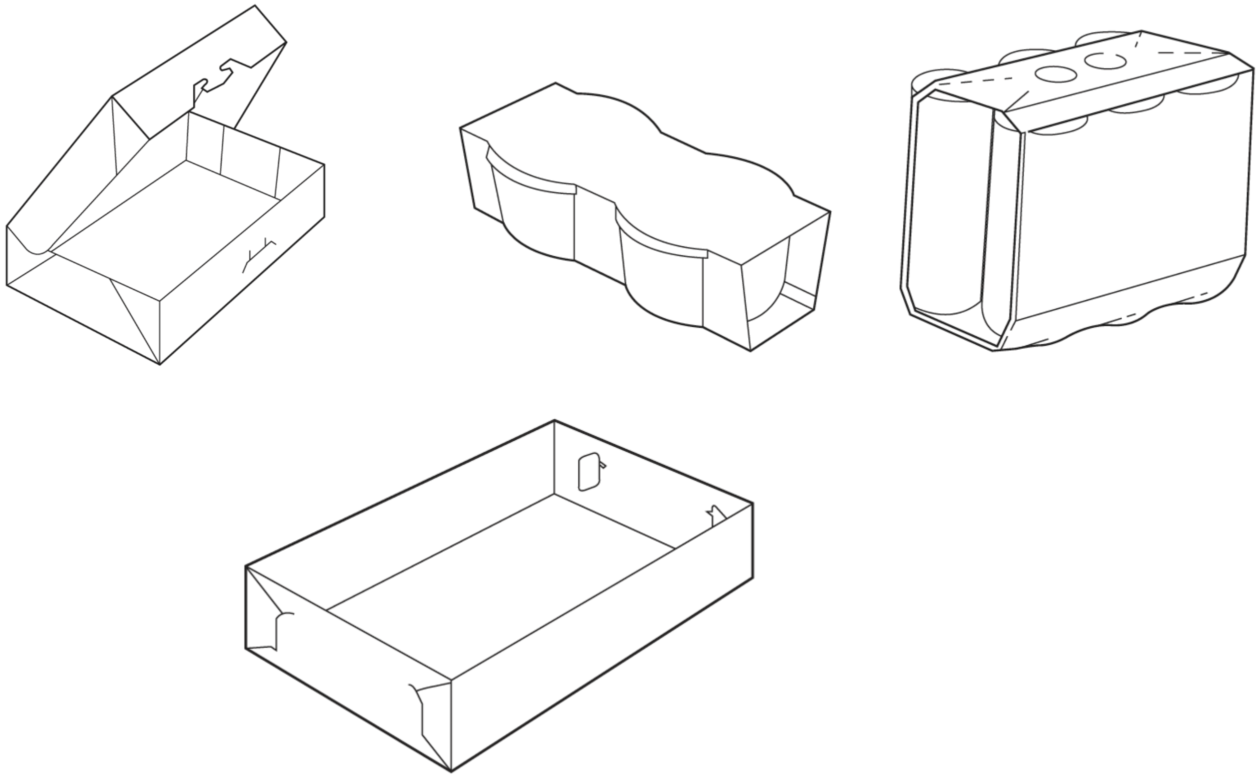


Figure 21. *Some End loads carton design: Box, tray, multi-pack.*

c. Carton making

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

1. Printing

Prior to printing, the paperboard is conditioned, either in the warehouse or by the side of the printing press, for 72 h. This is to ensure the material is consistent, especially with respect to moisture content.

The main three print methods are: offset lithography, which is normally sheet fed, and gravure and flexography, which are normally reel-fed.

2. Cutting and creasing

Cutting and creasing is carried out using a flat die for sheet-fed materials or a rotary die for reel-fed materials. If the cartons are not cut and creased correctly, their performance will be impaired during the following stages of conversion, filling and distribution.

Cut and creased using a forme, is made from plywood with steel cutting knives and creasing rules inserted into grooves which are commonly cut using a laser for high accuracy, enable the cutting to be controlled, a counter plate is placed on the base of the press, exactly in line with the forme.

Special foam rubber pads are placed at either side of the cutting knives to act as springs which remove the board from the blade after the cutting operation.

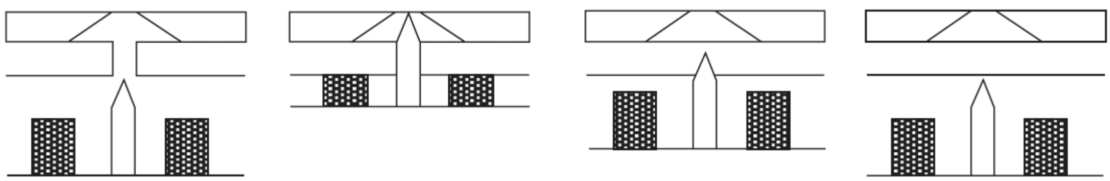
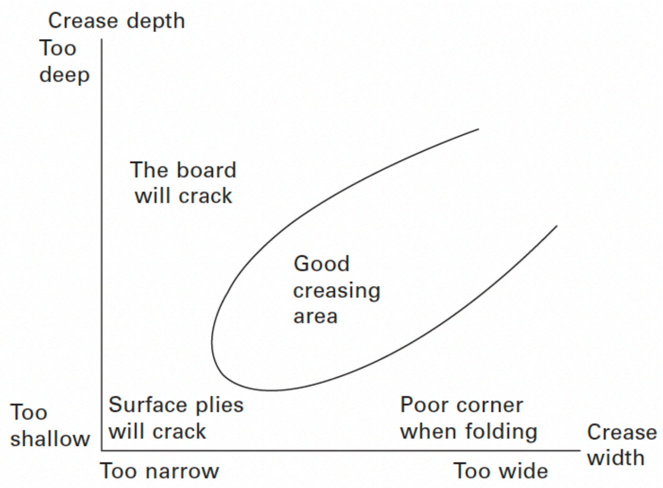


Figure 22. *Cutting and creasing forme with make-ready counter*

The other important operation performed by the forme is creasing:



- ✓ *The height and width of the creasing rule with respect to the paperboard being creased – the creasing rule is designed for a narrow range of paperboard thicknesses;*
  if the length of the rule is too long → damage the crease area,
  too short → produce an imperfect crease.
- ✓ *The thickness of the make-ready is too thin, the crease has no room to form properly*
- ✓ *The width of the make-ready groove in relationship to the thickness of the creasing rule*
  if the make-ready groove is too narrow → the crease is likely to form too tightly;
  too wide → is not tightly controlled
- ✓ *the accuracy and hardness of the make-ready is critical otherwise the crease will be poorly formed.*
- ✓ *the pressure of the die cutter – if the pressure is too great, undue forces → causing it to split*
  too weak, insufficient forces → form a imperfect crease.

The 'make-ready' mentioned above refers to the underside of the creasing platen situated beneath the substrate. Make-ready matrixes come in three forms:

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

The cutting knife blades are not continuous, they leave nicks between the individual carton cut-outs. This enables the individual cartons to be held together as if they were one sheet when the waste is stripped away.

The nick is made by designing notches into the cutting knives. These vary depending on paperboard type and thickness; the stronger the board the narrower the notch

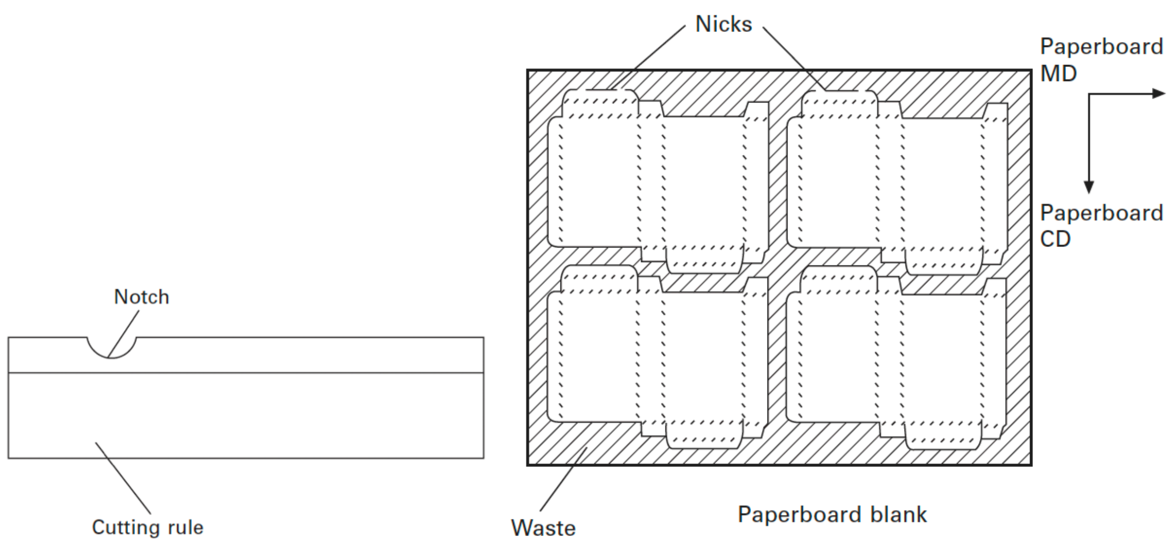


Figure 23. *Die-cutting rule with a notch and position of the nicks*

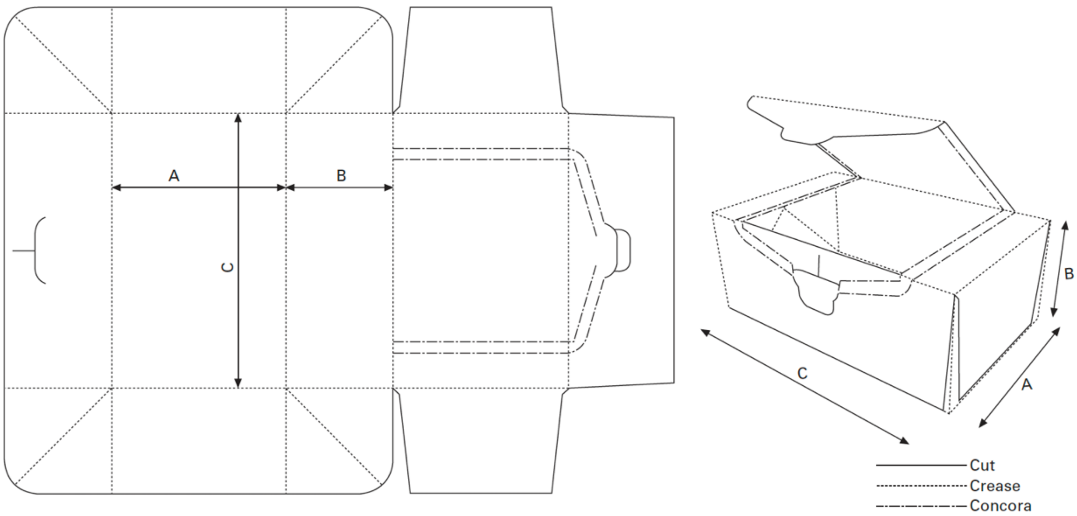
The strength requirement of the nick depends on many factors. These include:

- ✓ *Grain direction of the paperboard → MD is stronger than CD*
- ✓ *Method of making the notches →quality of notch must maintain the integrity of*
- ✓ *the carton within the sheet without breaking.*
- ✓ *Strength of the foam rubber to release the board from the knife →causing it to break prematurely*
- ✓ *Dimensions of the nick – normally 0.4–1.0 mm*
- ✓ *Number of nicks per cut edge, how the nicks are arranged – more nicks, more strength*
- ✓ *Moisture content of the paperboard – as mois. Content increases the strength of the nicks decreases*
- ✓ *Quality of fibre used to make the board – the weaker or more inconsistent the fibre, the wider the nick needs.*

3. Window patching (Optional feature)

At the cutting and creasing stage, opening features, which can be included embossing and cut outs, with the two most commom being the 'zipper' and the 'concora'.

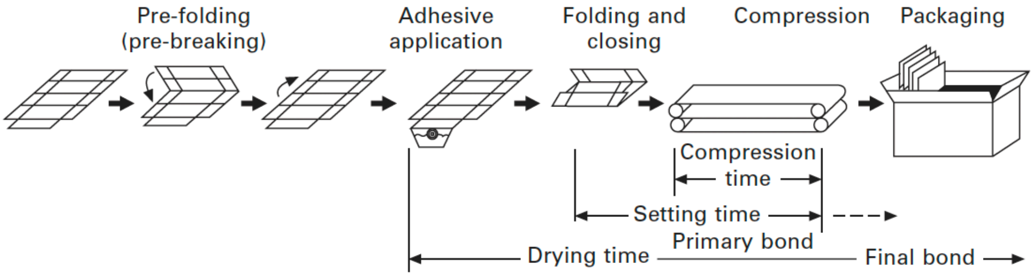
- ✓ *The zipper is produced by cutting a series of tram line perforations through the board, which allow the carton to be zipped open at the consumer's convenience.*
- ✓ *The concora method is more sophisticated and does not pierce the paperboard, but makes a stepped parallel double half cut (60%) from either side of the paperboard.*



Then, the cartons can be window patched if required. Adhesive is applied to an area around the window, far enough away from the edge so that the adhesive will not spread into the window but close enough to produce a secure seal.

4. Gluing. (Non-apply for mechanical lock)

Most end load cartons are pre-glued prior to delivering to the packer/filler, a high-speed operation, briefly described as follows:



- ✓ *Flat cartons are accurately fed into the gluer.*
- ✓ *Working creases are pre-broken by folding through 160°.*
- ✓ *For difficult substrates, the surface to be glued is broken to allow for better adhesion.*
- ✓ *Glue is applied to one of the two surfaces to be glued – often colored pink or blue mark so it can be seen to apply. Pressure is applied and the bond held until the glue is set.*

2.2.2 The normal quality chekcs:

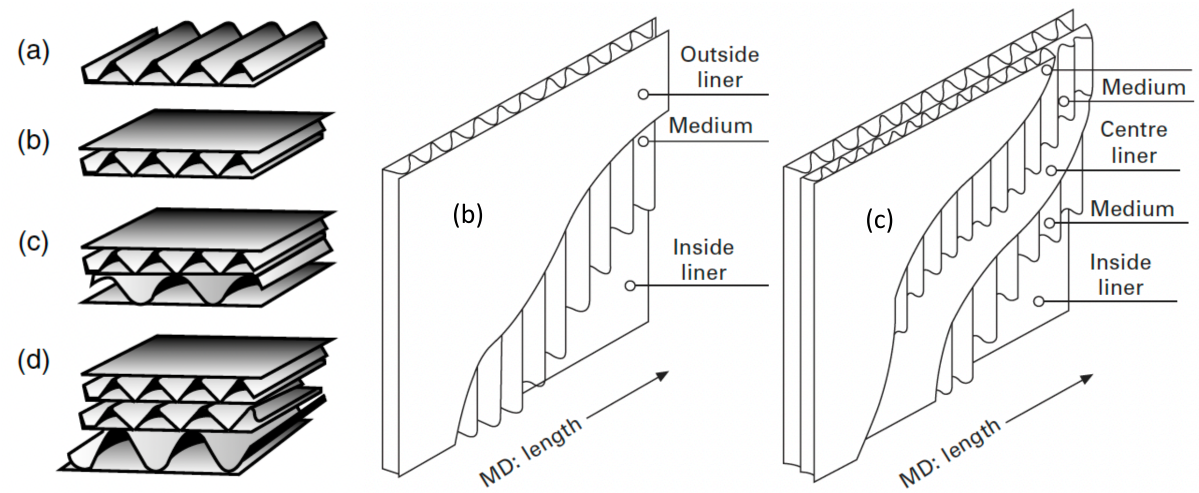
1. Graphics and text to agreed specification.
2. Coefficient of friction – *If coating is required*.
3. Dimensions.
4. Stiffness (MD and CD).
5. Moisture content.
6. Crease bend resistance.
7. Fibre tear on glue flap.
8. Carton weight.
9. Carton compression strength, Bursting strength.
10. Taint and odour.
11. Direct food contact – all food packaging must comply with current food contact legislation.

2. Corrugated Board Packaging

3.1. Structure of corrugated fibreboard

Corrugated fibreboard is the most popular packaging in the world for the storage and distribution of goods. Also, corrugated fibreboard is used for as advertising and brand promotional support depending on high printing quality developed to carry out information and artwork.

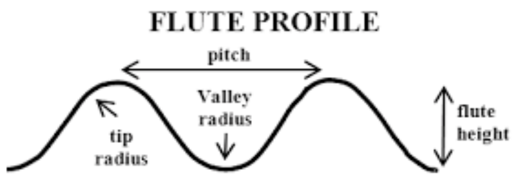
Corrugated board is a light, high-performance materials with a structure include two outside papers with a corrugated shaped paper in between. This structure helps them to have a higher thickness similar to an air-cushion. The outer papers are known as liners and the corrugated shaped paper is known as fluting or medium. They can also be produced with two or three layers to increase its strength.



Corrugated boards: (a) single face, (b) single wall, (c) double wall and (d) triple wall

The fluting shape is formed using heat, moisture and pressure by corrugated shaped rolls. Typical values for flute profiles and resulting board thickness defines the flute profile.

Flute type	Flute pitch (mm)	Take-up factor	Board thickness (mm) incl. papers
K	12	1.6	6.5
A	9	1.5	5.0
C	8	1.45	4.2
B	6.5	1.35	3.0
E	3.5	1.25	1.7
F	2.4	1.25	1.2
G	1.8	1.25	1.0
O	1.25	1.15	0.7

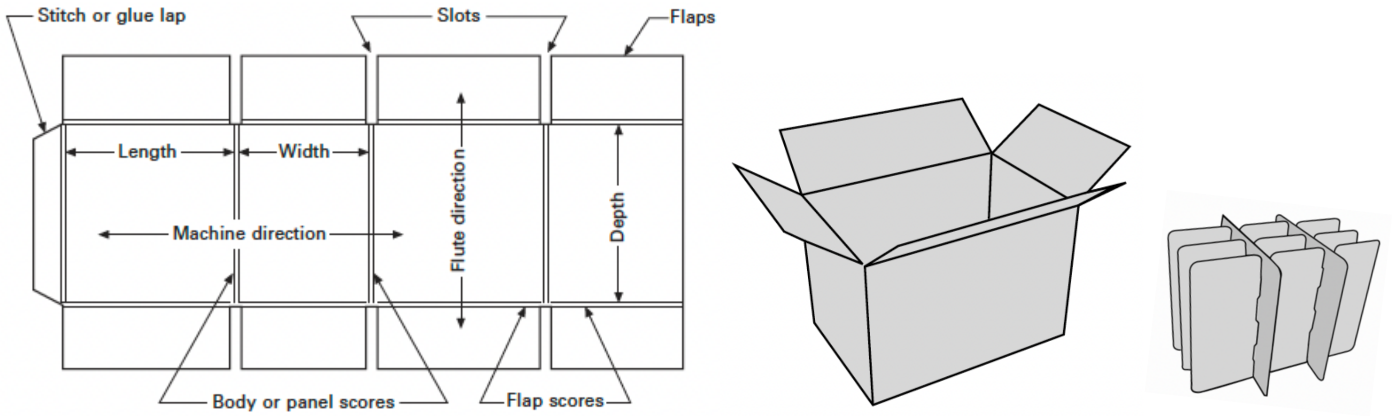


The flute profile sizes are indicated with a single letter to define their pitch, the number of flutes per unit length and the take-up factor. The pitch is the distance between two fluting tips. The take-up factor defines the length of the fluting (medium) paper used in a corrugated structure compared with the length of the liners.

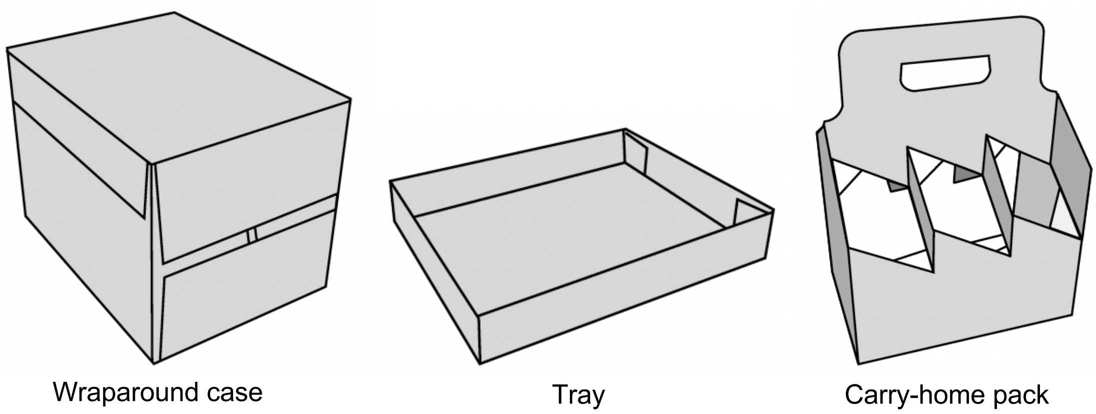
Flutes include arches that help resist bending, pressure and support weight such as cushions. An arch of proper curve produces the strongest way to span space between U and V (also has its advantages). Flutes also act as an insulator to protect against sudden temperature changes, providing strength; and protecting from damage. When comparing commonly used flute types with the same three paper, their properties shown in below table.

Characteristic	A-flute	B-flute	C-flute	E-flute
Stacking strength	Best	Fair	Good	Poor
Printing/ Die-cutting	Poor	Good	Fair	Best
Puncture	Good	Fair	Best	Poor
Storage space	Most	Good	Fair	Least
Score/Bend	Poor	Good	Fair	Best
Cushioning	Best	Fair	Good	Poor
Flat crush	Poor	Good	Fair	Fair
Anti-moisture absorption	Poor	Good	Fair	Best

On the other hand, it is important for the corrugated board that their packaging application (box or carton) has a rectangular cross section with top and bottom flaps. All flaps are the same length from the score (crease) to the edge of the flap. Typically, the major flaps meet in the middle and the minor flaps do not. This is known as a regular slotted container (RSC).



(a) Regular Slotted container (RSC) and a full depth divider in case known as partition



(b) Some popular packaging cases use corrugated board. (Source: Smurfit Kappa)

The corrugated board package could be designed various dimension and optimised for its intended use. There is a wide choice of papers for each liner and fluting, selected flute profile and modified flute (*e.g R-flutes are smaller and closer together than B-flute, resulting in the better printing surface and 20% lower caliper, meaning more board can be shipped per pallet)*, along with a large variety of printing and converting equipment available it can be produced cost-effectively and for many usage purposes. The functionality of a corrugated packaging is a determining factor in its design and use including:

- ***Packing lines:*** involved in using erection and closing equipment (wrapping around) or top/bottom carton taping machine.

- ***Palletisation and logistic chain*** are the main function of containing and protecting packed goods during storage and distribution. Good layout and palletisation of the corrugated boxes on the pallet concerning the utilisation of the volume, stackability and overall stability.
- ***Communication:*** requires printing to identify the contents, provide legal and regulatory information, and bar codes for routing. Besides, they can be used for marketing, merchandising and point-of-sales thanks to high graphics and catching eye contents.
- ***Retail-ready:*** should satisfy the "five easier" characteristics including identity, open, shelf, dispose and shop requirements for retailers and in-store logistics.
- ***Product safety:*** protect goods from the environment and during transportation. There are no hazards contaminating to the contained products or exposing surroundings.
- ***Recycling and sustainability:*** recyclable and other materials easy to remove during the pulp preparation in the paper mill.

3.2 Manufacturing process

3.2.1. Overview and materials for corrugated board production.

There are four main stages in the production of corrugated fibreboard packaging including:

- Corrugated board manufacture: Single-wall, doulde wall or triple wall
- Printing: Post-printing (process flexo, digital printing, etc.) or Pre-print (Offset or High-quality flexo)
- Cutting, scoring (creasing) and gluing if any (taping or stitching)
- Wrapping and storage.

A – Paper types

The four basic paper types used for corrugating (recycled and virgin, liner and fluting) all have their unique selling points. The virgin fibre-based paper is a world market and the recycled-based paper is a regional market.

Paper type	Grammage	Characteristic
Kraft paper	115–440 g/m^2	Pure virgin fibres from chemical pumping process.
Kraft Liner		Contains at least 70% wood pulp, the rest is recycled fibres, long fibres with good all performance and it is suited for rigorous conditions.
Test liner (coated or uncoated)	100–300 g/m^2	Controlled sources of recovered fibers, contains shorter fibres. Thicker lower layer, couched with a high-quality liner web, average strength and no extreme demands.
Semi-chemical fluting	115–275 g/m^2	Long virgin fibres give great rigidity and resistance to impact, good all performance and it is suited for rigorous conditions.
Recycled-based fluting	75–175 g/m^2	Only good quality recycled raw materials are used, short fibres with average strength and no extreme demands

Liners can be white (bleached) or brown (unbleached) and have several main functions is:

- To absorb and deflect static and dynamic forces such as tension, impact, pressure and bending
- Having a smooth surface for obtaining good printing
- Having coarse reverse side which helps the fluted webs and liner papers to adhere firmly together.

The properties of corrugated board are determined by the quality and features of the paper:

- Mechanical properties: Strongly oriented with MD is greater than CD properties. This property is dependent on type and length of fibres, and used additives.
- Optical properties
- Production properties following paper properties can be specified

Paper type	Required characteristic
Liner (outer)	SCT CD (or RCT), Burst, moisture, friction, porosity, dennison wax, Cobb value, colour, brightness, roughness.
Fluting (medium)	SCT CD (or RCT), CMT liner, moisture, friction, porosity.

B – Adhesive (Binders) & Decorating agents

Standard corrugated board is made with a starch-based adhesive applied at about 10–14 gsm. This type is popularly used in producing corrugated boards in both pre-print and post-print, it consists of a carrier (surfactant) or cooked starch component, a raw starch component, caustic soda and borax, all are prepared in water and mixed uniformly in a 'kitchen'. Where higher resistance is needed, starches can be modified by adding various polymers.

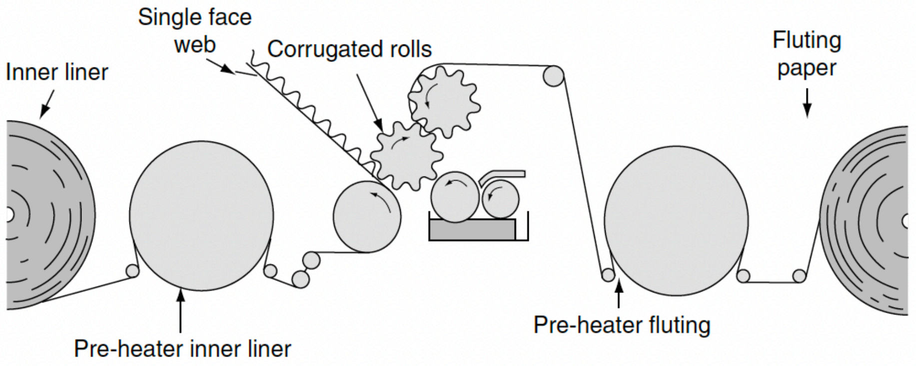
Cold adhesives, such as polyvinyl acetate (PVA) are normally used to create extremely strong bonding corrugated sheets. Generally, the cost of using PVA is normally greater than starch in corrugated board manufacturers but uses less energy and higher strength compared to starch adhesives at high moisture levels.

The printing ink used to decorate the corrugated packaging is normally water-based ink for flexo printers and oil-based ink for offset printers. Water-based or oil-based coating relatively is applied to protect printed images and create visual effects.

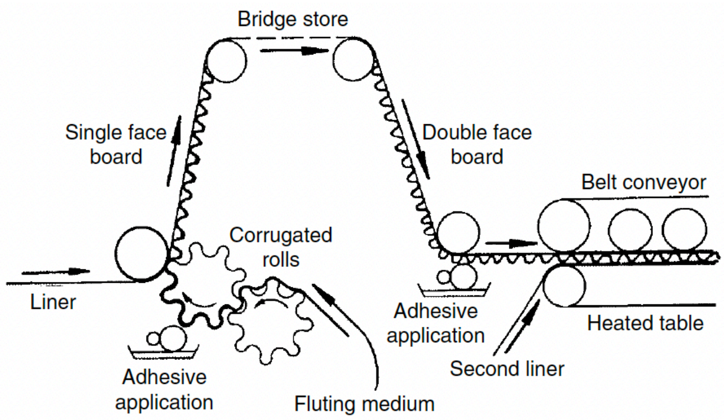
3.2.2. Corrugated board production

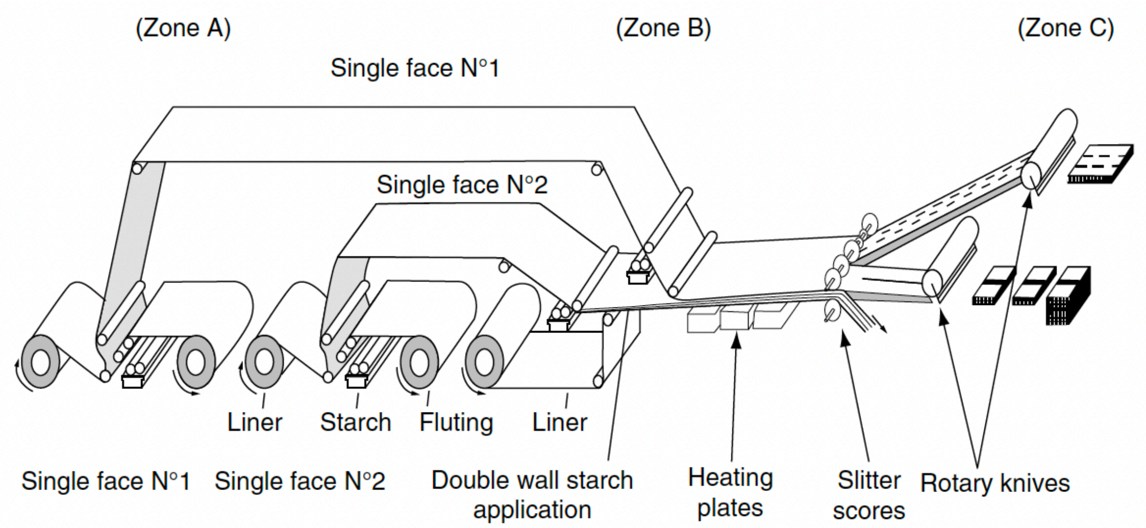
The production of the corrugated board is carried out in several stages in-line:

- **Production of the single face corrugated board**: Heat and steam used to make paper pliable enough to form and retain the flute shape. The flute shape is formed by pressing between two profiled corrugator rolls in the 'fingerless' process, or one profiled roll using a vacuum.
  The starch adhesive is applied to the tips of the flutes, and then the fluting paper is combined with the liner which is conditioned to bring the same temperature and moisture content as the fluting paper.



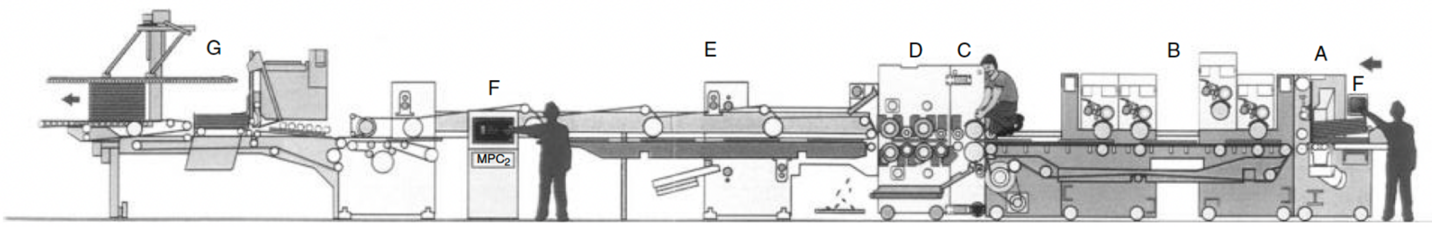
- A second liner is applied at the double backer to produce single wall (double face) and triple wall corrugated board such as figures below:





In fact, the speed of the single facer is more than that of the double backer, so the excess board accumulates in a bridge system between the two lining stations balancing the difference in speed.

- **Cutting and scores**: After passing through a drying section, the board is matured and cooled before being slit and cut to the required width and length. Scores (creases) may also be applied to the board in the machine direction of the corrugator.
- **Flatness of corrugated board**: Corrugated board sheets often exhibit curvature such as warp or curl due to moisture change, which can cause great difficulty in subsequent converting operations and in box set-up in the end-user's facility. The warp phenomena of E and F flutes are much greater than C flutes. A flatness solution is popularly applied to reduce this matter by pressuring board sheets and wrapping them in PE film to avoid humidity interference.
- **Die-cutting:** There are two types of flat bed and rotary die-cuttings. The accuracy in the CD of the rotary die-cut is good, but the slip of the sheet reduces the accuracy in the length direction.
- **Gluting:** The side seam of the carton is completed adhesive by a folder-gluer unit or stapler if required.



E.g. A Martin machine is a modern in-line carton production machine where the combination of these machine units such as touch-control (F), sheet feeds (A), flexo printing (B), rotary die-cutter (C), slotting (D), folder-gluer (E) and packing (G) units.

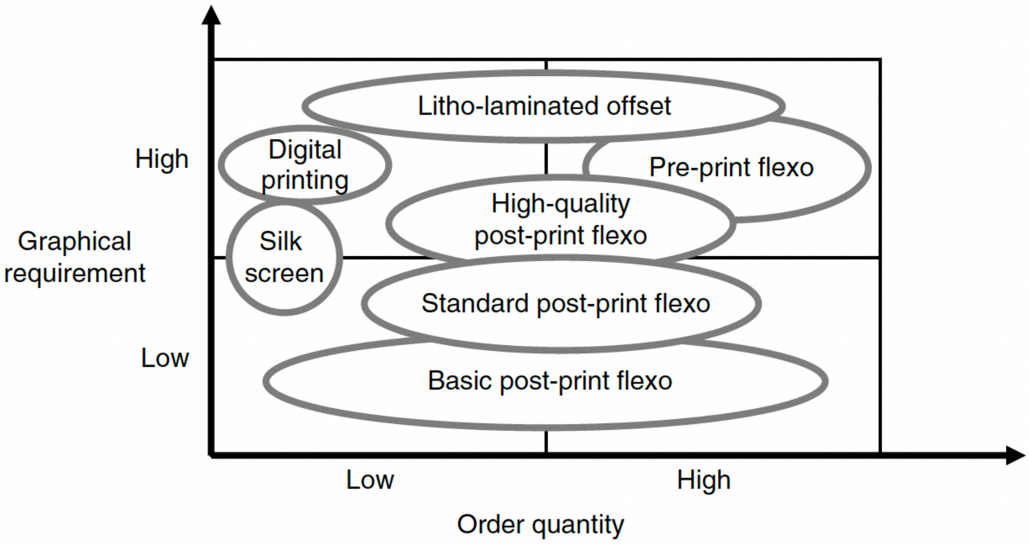
3.2.3. Corrugated board printing

The printing techniques used for corrugated board can include:

- Flexographic Post-print* (or "letterpress" process): Normally sheet feeds printing.
  - Basic flexo post-print
  - Standard flexo post-print
  - High-quality flexo post-print
- Flexographic Pre-print: It can be reel-to-reel or reel-to-sheet printing formats.
- Litho-laminated offset Pre-print
- Digital printing (inkjet)
- Screen printing.

*Note: *Pre-printing means that the printing is done after the corrugated board sheet finishes while pre-print** is the reverse process, where the outer paper is printed first and then laminated onto the single face corrugated board.*

The application of the different techniques is dependent on the relationship between the graphical requirements, the print quality and the order quantity shown as figure below.



Wash-boarding phenomena can appear if low-grammage papers are used in the outer liner in some cases. It is difficult sometimes to obtain good results such as an illustration in solids and halftone or a bar code. Pre-print may diminish this issue compared to post-print.

The halftone image causing by wash-boarding phenomena.

3.3. Testing corrugated board materials and packaging

3.3.1. Typical test methods for corrugated board

1. *Board weight (unit is g/m^2 or lb/ft^2)*

   (TAPPI/ANSI T410 om-23 or ISO 536) is measured under standard conditions: 23°C and 50% RH or calculated from the paper grammages using a simple linear formula to estimate paper consumption.

   Board weight = outer liner + (take − up factor x fluting) + inner liner + glue

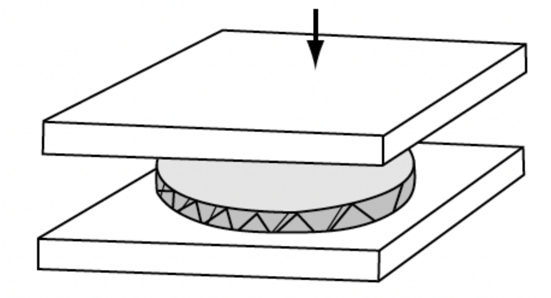
   For example: A structure of board is KT150/CA125/KT150 g/m^2, C-Flute. Glue thickness is not counted.

   Board weight = 150 + (1.45x125) + 150 ~418.25 g/m^2

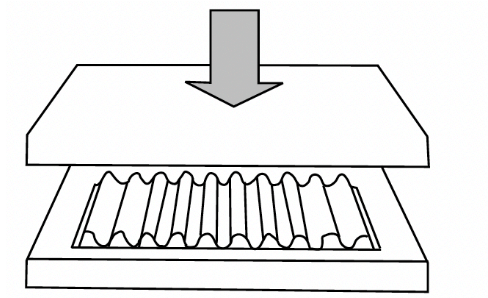
2. *Thickness (mm or cm)*

   (ISO 3034:2011 or ISO 534) is measured between a plunger and an anvil with 20 kPa.

3. *Flat crush strength (FCT) (lb/in, kN/m)*
To determine the ability to retain structure and geometry of fluting. A first estimated approximation could refer to a good relationship between the FCT of the board and the CMT (Concora Medium Test) strength of the flutes.



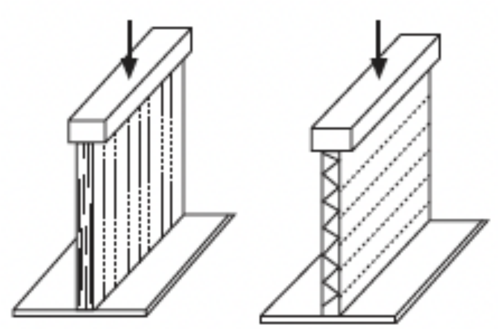
Flat crush corrugated board testing (ISO 3035)



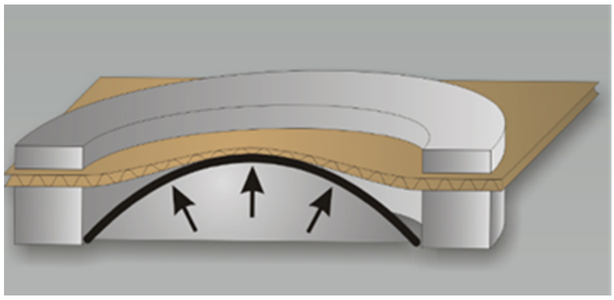
Concora Medium Test apparatus (ISO 7263)

4. *Bending stiffness (or Rigidity)*
(ISO 5628:2012) the force required to deflect a flat specimen of corrugated board. It effects the performance of the packaging used such as folding characteristic, etc.

5. *Edge crush test (ECT) (lb/in, kN/m)*
(ISO 3037-2007 or TAPPI 811 om-11) is used to evaluate the compression strength of the corrugated board.



Edge Crush Test (ECT)

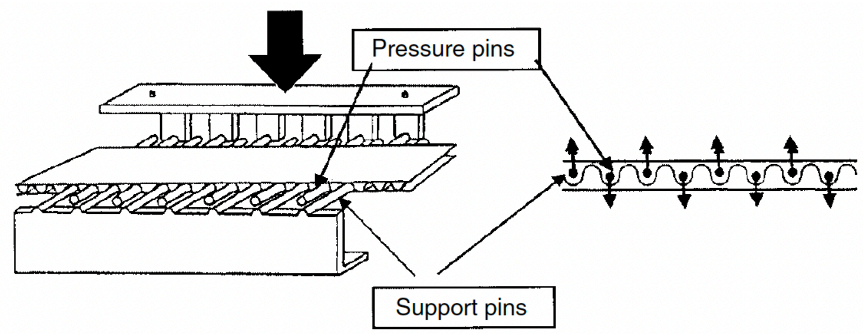


Bursting Strength

6. *Bursting strength (kPa or Psi)*
(ISO 2759:2001) is a commonly used measurement in a large range from 800 to 8000 kPa for classifying the quality of the corrugated board, depending on the grammage and the nature of the liners.

7. *Puncture test (Beach units with each unit is equal to 0.0299 joules)*
(ISO 3036:1975, FEFCO TM5 and TAPPI T803) To measure the energy required to penetrate the corrugated board which helps to evaluate damage-ability can occur during transportation.

8. *Pin-adhesion test (PAT) (N/m)*
(TAPPI T821 om-12 and FEFCO TM11) is used to evaluate the adhesion between the fluting and the liners.



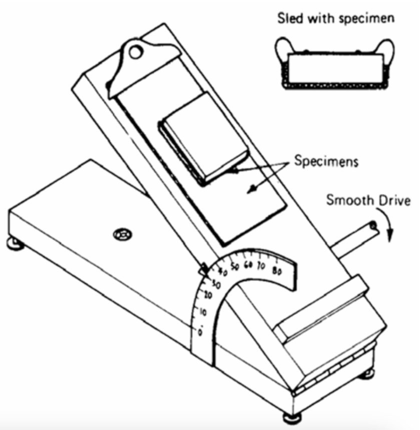
9. *Moisture content (%)*

The procedure for moisture measurement is by a gravimetric moisture analysis. Water is removed from a pre-weighed sample in an oven. and then the moisture content is calculated as formula follows:

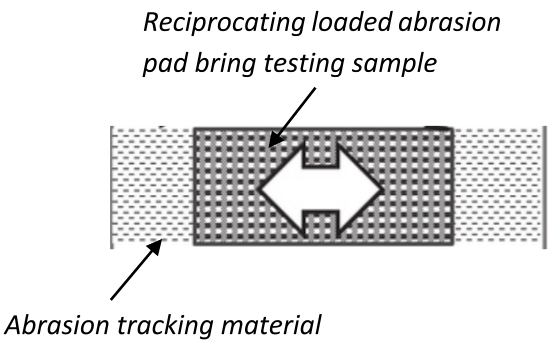
$$\textit{Moisture content} = \frac{\text{Initial Sample}_{\text{wet}} - \text{Sample}_{\text{dry}}}{\text{Sample}_{\text{dry}}}$$

10. *Resistance ability of paper surface.*

❖ Friction test (or coefficient-of-friction (COF)) determines the rate at which the packaging materials can slide against each other – possibly causing movement and slippage within the unit load or damaging the packaging materials.



Inclined plane method (TAPPI T815 om – 01)



Rub test protocol per ASTM D5264

❖ Abrasion resistance (ASTM D5264-98) is performed by rubbing a printed surface against a substrate to evaluate scuffing resistance, and ink peel-off as well.

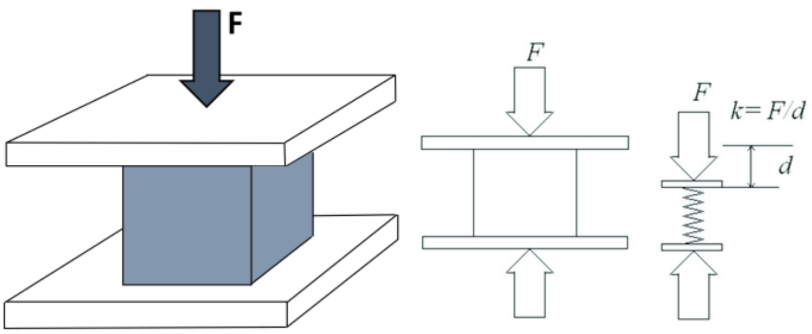
3.3.2. Test method for Box

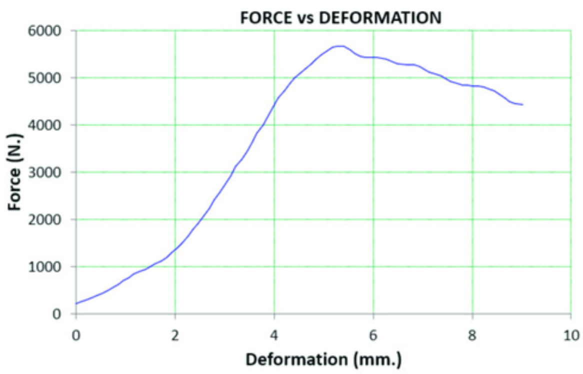
1. *Internal and external (blank) dimensions*

The size of a box can be measured for either internal (for product fit and order purpose) or external (for packing and handling machinery or palletising) dimensions.

2. *Box compression test (BCT)*

BCT is used to measure stackability which simulates the top-to-bottom compression strength. BCT can be measured in an empty box such as FEFCO method or a filled box as ISO 12048:1994. However, the result can be different due to empty versus with content, fixed or loose flaps and the testing speed of each method.





In other ways, the prediction of the box performance can be carried out to reduce the time and effort to determine the specification and suitable design of the corrugated board to be used. The most widely known formula which links the box compression strength with the mechanical properties of its components is the one devised by McKee (1963):

$$\textbf{\textit{Box compression strength = 5.87 × ECT x (BP × T)}}^{1/2} \quad \textbf{\textit{(kN)}}$$

where ECT = Edge Crush Strength = $k \times (\Sigma RCT_{Outer} + (e \times \Sigma RCT_{Medium}))$ (kN/cm), BP = Inside perimeter of box = 2(L + W) (cm), and T = corrugated board thickness (cm).

Flute	k (Flute rate)	e (Take up ratio)	H
B	1.20	1.38	0.3
C	1.15	1.50	0.4
A	1.10	1.58	0.5
BC	1.20	2.88	0.65
AB	1.20	2.96	0.75

<u>*Remark:*</u> $BCT_{McKee} \geq BCT_{required}$

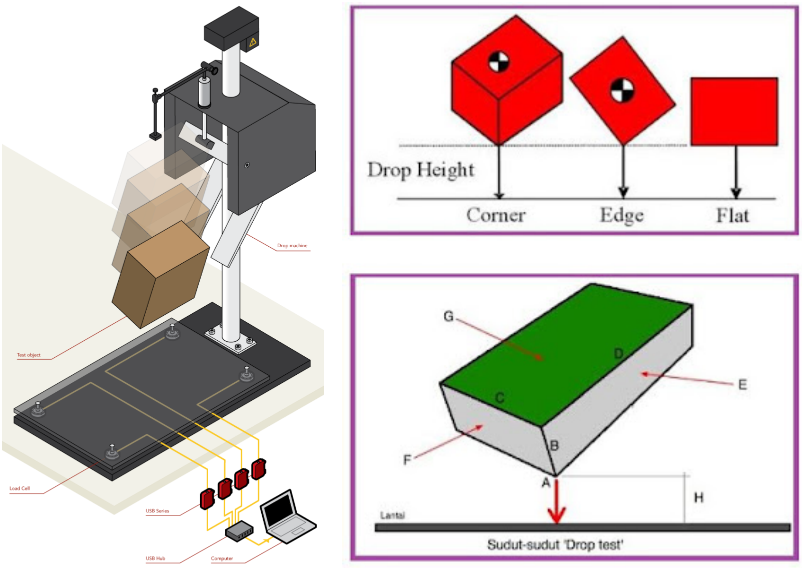
BCT Required = SF x (n-1) x W
W = Gross Weight (kg.)
n = Number of boxes stacks in the unit load

$$\text{*SF} = \text{Safety factor} = \frac{1}{f_H f_{RH} f_S f_T}$$

1. The effect of moisture (fRH)
2. The effect of storage time (fT)
3. The effect of stacking pattern (fS)
4. The effect of number of handling (fH)
5. Others *(Printing Area and so on)*

3. Transportation test

Drop testing is carried out according to ISO 2248:1985 standards. The evaluation of corrugated board packaging is performed on box packed with sand weight from 8 to 15 kg. There are different modes of drop, and height is increased incrementally during the test, finally result is depend on the percentage of boxes damaged at each height. For further testing, a vibration test is executed to simulate vibration during transportation which can cause much damage to products.

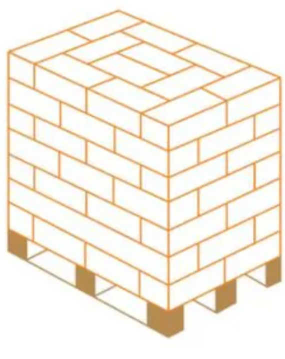


Drop test and Dropping modes

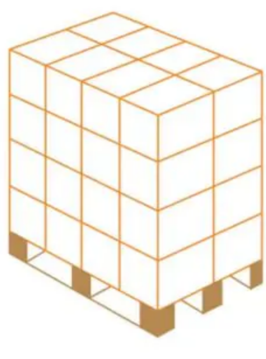
Vibration test

4. Pallet test

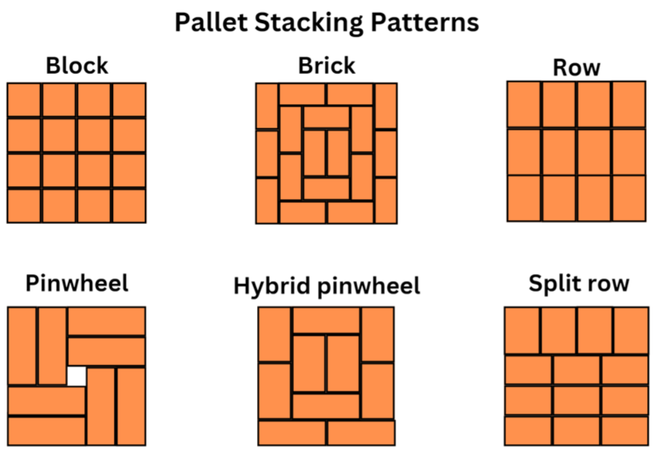
Depending on the logistics chain and storage requirements, the pallet can be palletised in other forms (figures below) for stability and subject to several test procedures such as vibration test, delivery test, etc.



Interlocking boxes



Stacked boxes

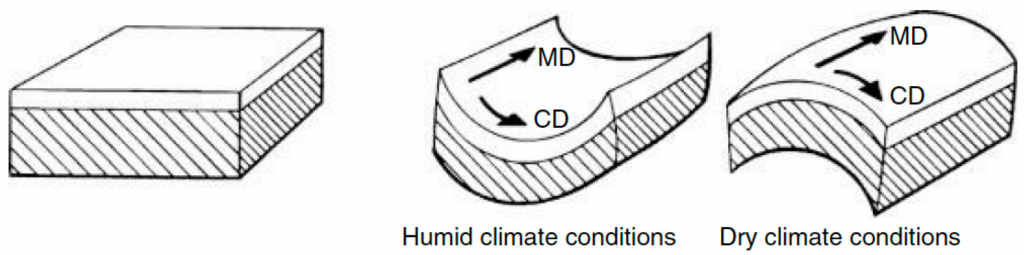


APPENDIX FOR PERFORMANCE PROPERTIES OF PAPER AND PAPER BOARD

A.1 - Performance properties of paper and paperboard

The main properties paper and paperboard vary depending on the grade and used specification in packaging applications are as follows:

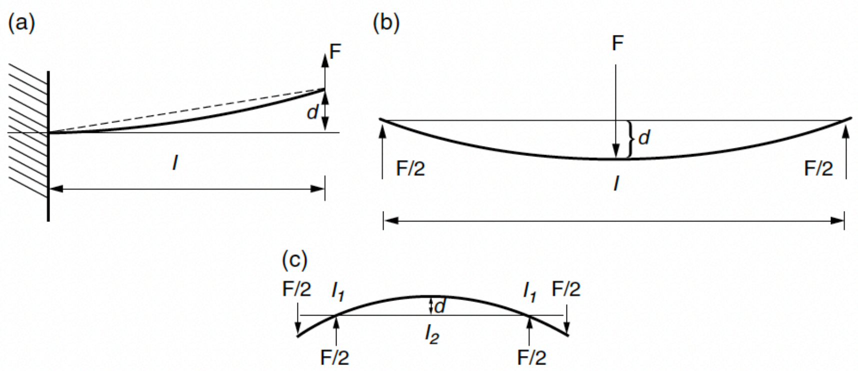
- ***Basic weight (***substance or grammage) is measured as weight per unit area (typically the units can be g/m2 or lb/ft2) and most of the strength-related properties increase with increasing basis weight.
- ***Thickness (caliper)*** is measured in either microns (0.001 mm or 1 x 10 $^{-6}$ m) or points (1 point is 0.001 in. or one thousandth of an inch) and closely more relevant to stiffness of paper and paperboard in a fixed basic weight.
- ***Printing surface*** includes the density, whiteness, porosity, flatness and smoothness of the bleached paper and paperboard, especially sulfide grades, portraying a bright high-quality print.
- ***Moisture content*** (a percentage of the dry weight) affect to changes in many strength properties. The cellulose fibre in paper structure will expand by absorbing moisture or shrink by losing moisture in RH condition changes. Moisture content is also relevant to dimension changes and flatness of paper and paperboard, shown in picture below, directly affecting MD and CD of paper sheet as well as operating of them is though printing and packaging manufacture.



The recommended percentage of RH in which paper and paperboard are printed, converted and used on packaging lines is 45–60%. In addition, paper and paperboard should use moisture-resistant wrapping in transit and storage before unwrapping for use as well as protection semi-product after each process.

- **Stiffness** (some tissue papers accepted) is related to other important features, such as box compression, creasability, foldability and overall toughness.as well as stands erect on shelf and its aesthetic appeal. The MD stiffness value is higher than the CD value, and sometimes this is expressed as the stiffness ratio.

  Stiffness of lightweight 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 (d) to measure bending stiffness, bending resistance and bending moment.



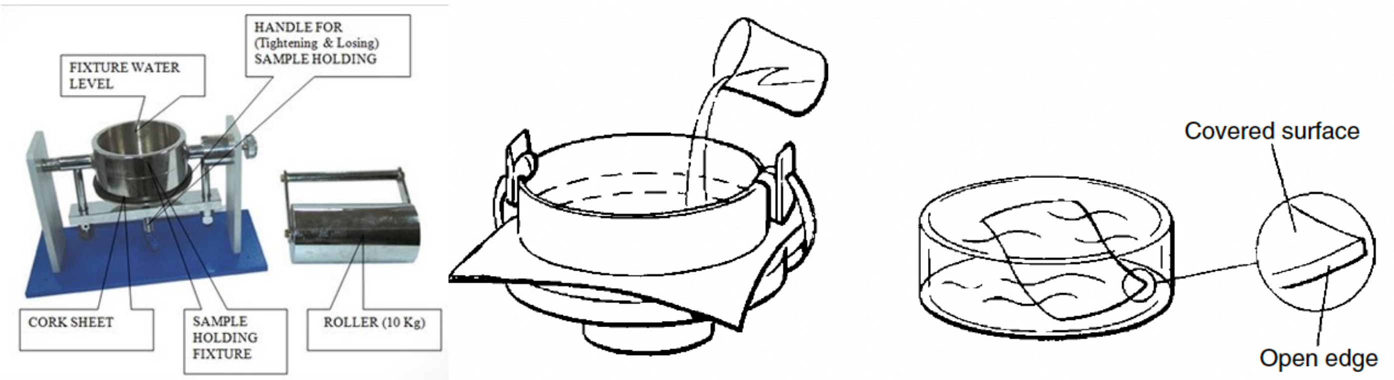
Loading principles for the measurement of paper and paperboard stiffness by the (a) two-, (b) three- and (c) four-point methods.

An important consideration regarding stiffness is that it is related to the modulus of elasticity (*E*) and thickness (*t*) (calliper) as follows:

Stiffness = Constant (material specific) $x\ E\ x\ t^3$

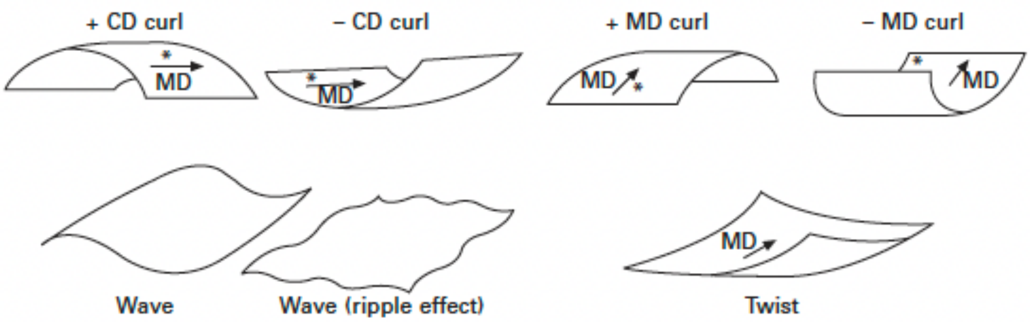
The index is lower than 3.0 for paper and paperboard but is still significant. For other types of paperboard, the index is around 2.5–2.6. Stiffness is also highly dependent on thickness as shown by doubling the thickness and noting that the stiffness increases by just over five.

- ***Absorbency or The Cobb value*** (water absorbency) and porosity value of paper and paperboard can be adapted to suit the required performance. Water-based adhesives ideally require an absorbent surface to dry and set the adhesive by fast water removal. This allows for efficient adhesion in bag, sack and carton making and labelling.



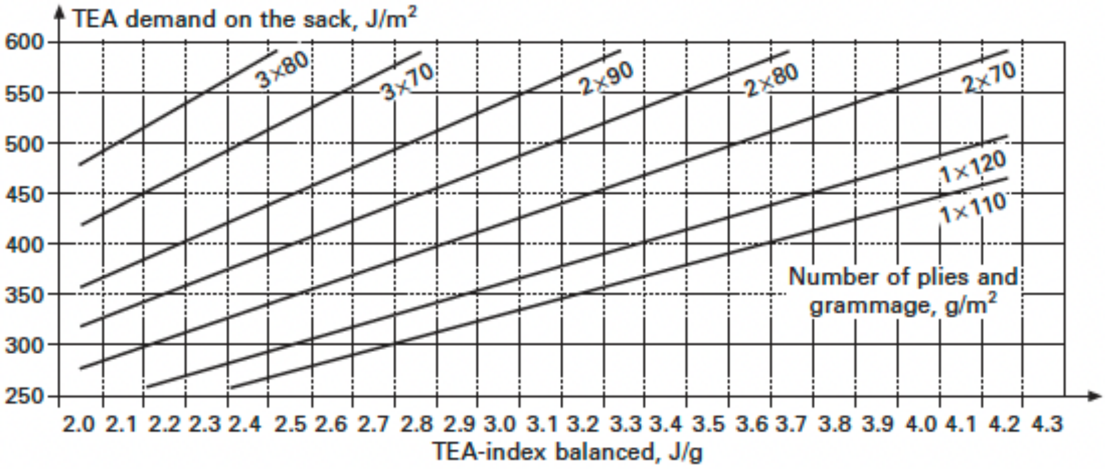
Cobb test for water absorbency

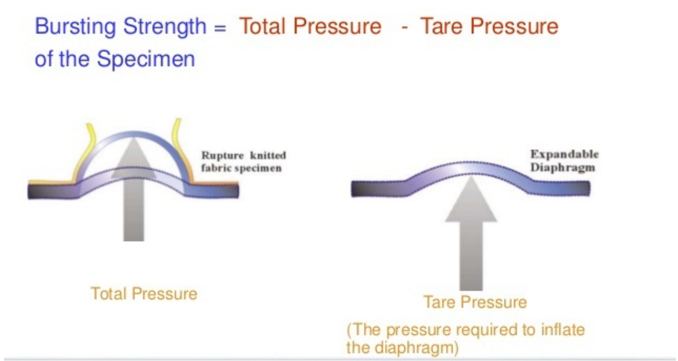
The Cobb value can be adjusted by 'hard sizing' the paper so that the fibres are protected from water, allowing use in frozen and wet environments without significantly reducing the physical properties of the paper. However, this can be a drawback if the paper is only coated on one side and the other can absorb moisture leading to its warp. Paper curling is a very serious issue if it's not controlled and can occur during or after manufacturing, therefore, moisture variation should be kept to a minimum.



Warping of paper and paperboard (= least absorbent side; + = greatest moisture gain; – = least moisture gain)*

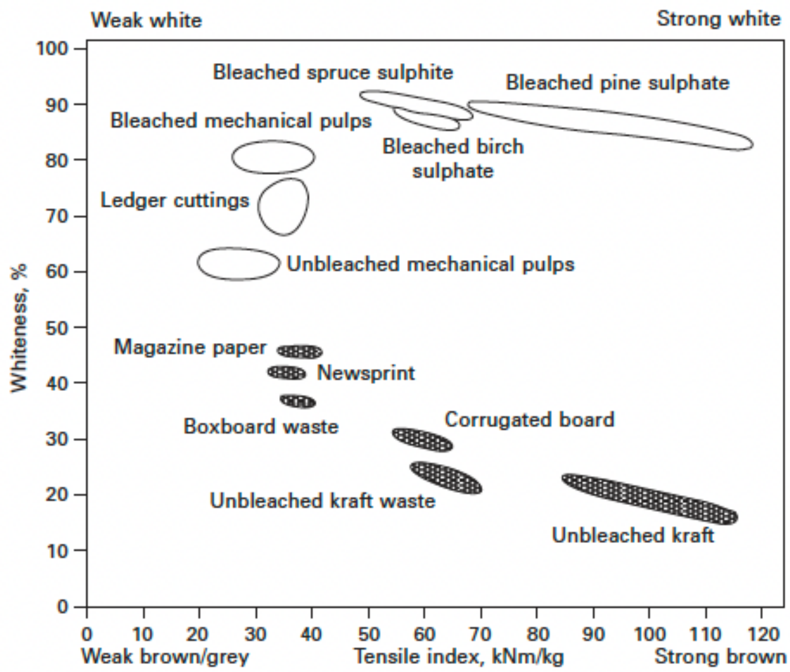
- ***Puncture resistance*** is only suitable for heavyweight material, such as paperboard. It is a measure of the maximum force or energy required to penetrate a material.
- ***Stretch or elongation*** is a measure of elasticity expressed as a percentage increase compared with the original length between the clamp. CD elongation is higher than MD elongation unless the material has been creped.
- ***Burst strength***, especially 'sack Kraft'. Paper can be micro-crimped to increase the burst strength and this helps to control and balance the total energy absorption (TEA) and enables it to be used for industrial packaging such as cement sacks and 500 kg flexible intermediate bulk containers.





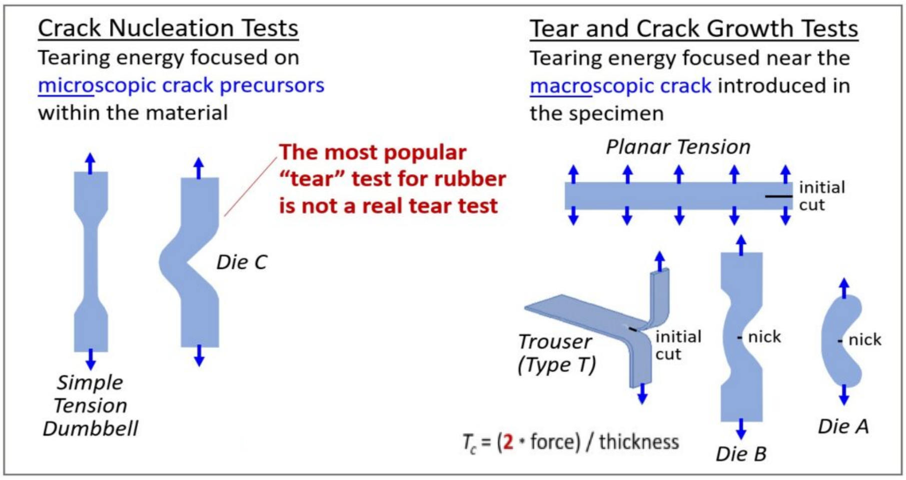
Total energy absorption (TEA) levels for different combinations of paper plies and weight.

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



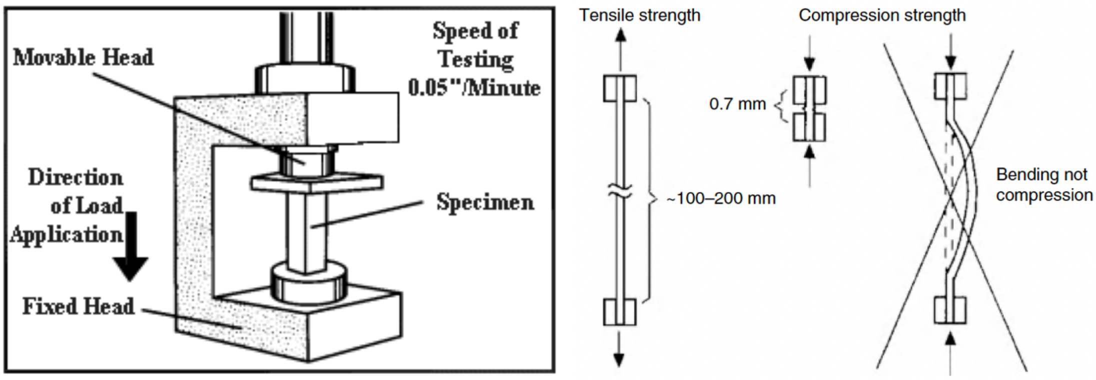
Difference in whiteness and tensile strength of primary and recycled paper and paperboard grades

- ***Tear resistance*** is the measured force required to produce a tear in the sheet from the starting cut to prevent damage due to tearing. Evaluate the ability to open and access contents, the requirement is for the material to tear cleanly.



Some tearing patterns are used popularly in tearing test. Source: Endurica

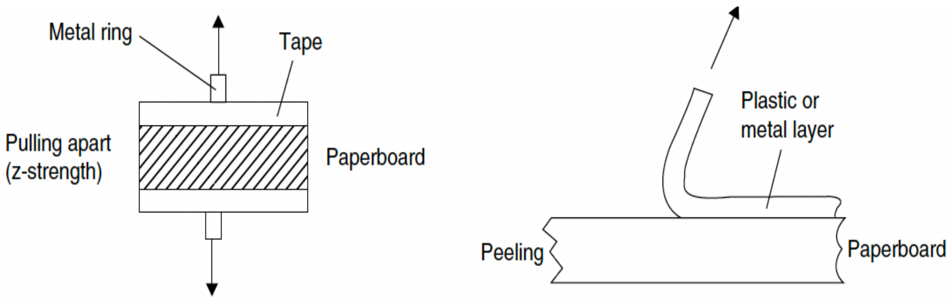
- ***Compression strength*** is relevant to box compress resistance to static and dynamic loads through storage and distribution conditions of the materials.



Compression strength testing - note difference in sample length compared with the tensile test. (the distance between the jaws of the test rig is no greater than 0.7 mm)

- ***Grease resistance*** of paper can be varying degrees, either by treating the fibres of paper physically (known as beating or refining) or chemical treatments including adding fluorocarbon to the furnish or at the size press, to produce grease-proof (GP) or grease-resistant (GR) papers.

  GP papers can be further treated by super-calendering to produce a translucent grease-resistant paper known as 'glassine'. Dissolving some of the fibres in sulphuric acid to produce parchment achieved ultimate grease resistance, and also has a very low gas permeability.
- ***Ply bond (interlayer) strength*** relates to the delamination of the material when subjected to forces perpendicular to the plane of the material, which cause delamination. The delaminating force is measured by TAPPI test or the Scott Bond test. 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.

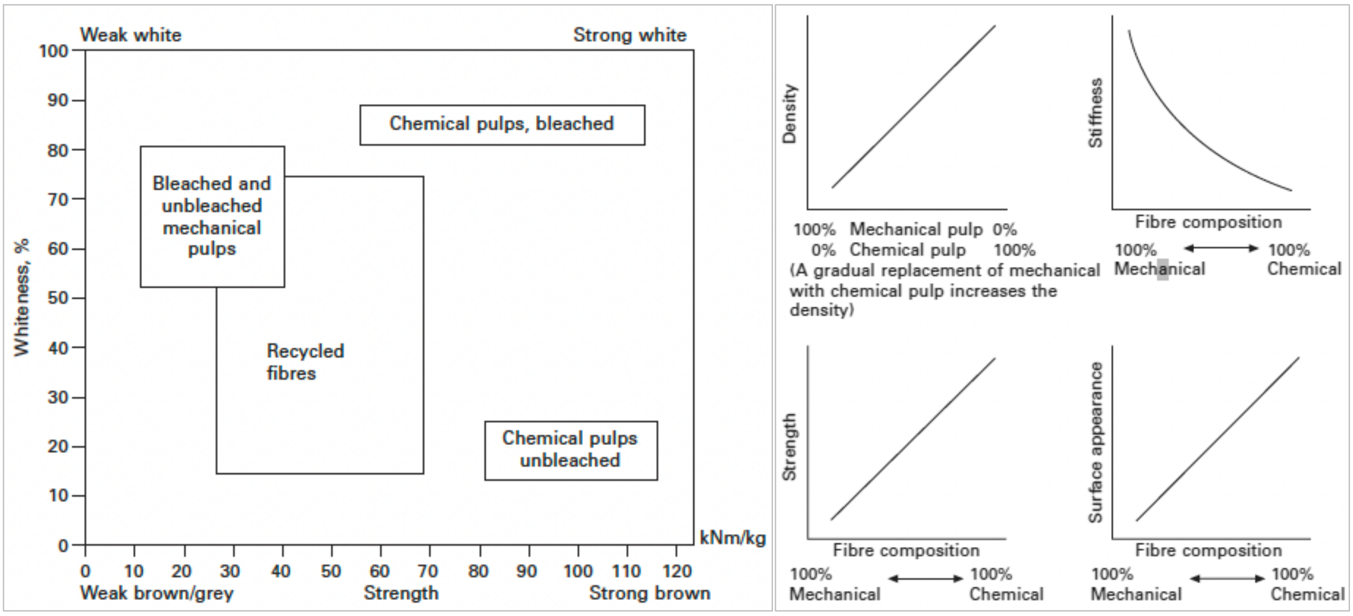


Principles of testing interlaminar strength.

Regarding these main properties of paper and paper board. The properties can differ between paper grades taking account of bleached vs. unbleached materials, and materials made from virgin chemical pulp, virgin mechanical pulp and recycled fibres. The comparison can include:

- Bleached chemical pulps are generally weaker than unbleached pulps but both are stronger than recycled and mechanical pulps. In that, recycled fibres are stronger than mechanical fibres. Also, bleached pulps are whiter than unbleached pulps whilst most recycled pulps are grey.
- Mechanical pulp is stiffer than chemical pulp but not as strong. However, the manufacturer can combine pulps for maximum overall performance, for example, folding boxboard (FBB) has inner plies of mechanical pulp and outer plies of chemical pulp provided that maximum stiffness at minimum grammage. four properties of mechanical and chemical fibres were compared in pictures above.

(a) Whiteness and strength of various pulps *(b) Effect on properties of changing types of pulp*



A.2 - Changing performance properties by combining paper with other materials

Paper and paperboard can acquire barrier properties and extended functional performance such as heat-seal ability, heat resistance, grease resistance, ultraviolet (UV) light barrier, gas and water vapour barriers, ect, 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.

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.

The negative aspects of combining paper with other materials are that their wastes are more difficult to separate and recycle into other parts commercially. Recently, water-based barrier coatings (WBBC) or 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 and their use does not impede biodegradation of treated paper or paperboard.

B – Appreence properties of Paper and Paperboard

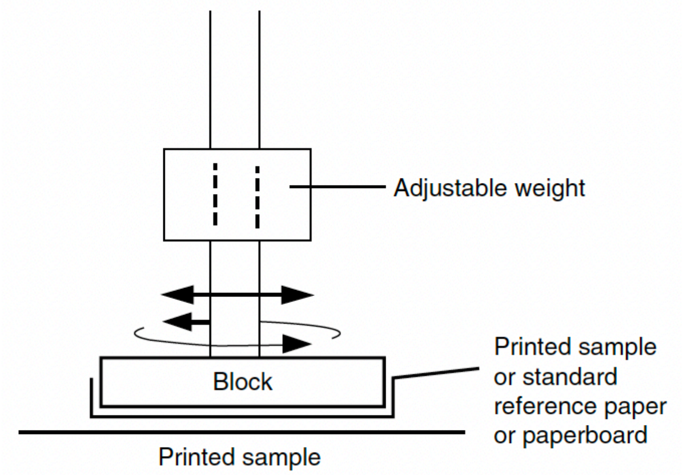
1. *Colour & Light fasstness*

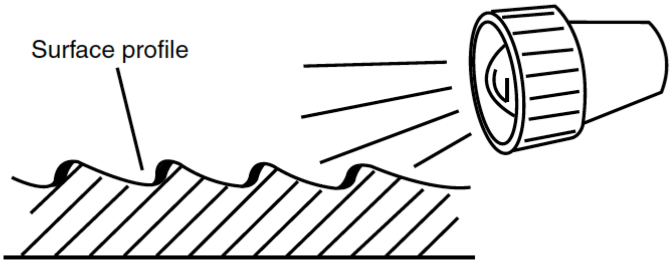
The color of paper and paperboard is usually white or brown, depending on whether the fiber is bleached or unbleached (brown). The outer surface, and sometimes the reverse side, may be pigment-coated, typically in white, although other colors are also possible.

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. They are also effected by the percentage of recycled paper in paper content.

→ *The element is to the inks, varnishes and sealers, and adhesives, must also be chosen properly.*

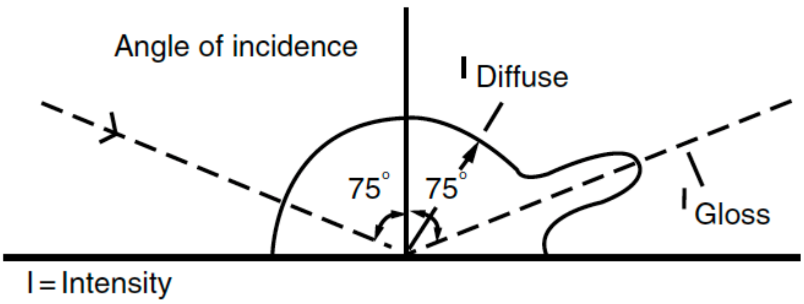
2. *Surface characteristics*

Surface Propertise	**Descriptive characteristics**	**Effect on**
Smoothness	An important aesthetic feature and is also functionally important with respect to printing and varnishing.  (a) Surface roughness, measuring principle of the Bendtsen, Sheffi eld and Parker Print Surf roughness testers. (b) surface roughness, measuring principle of the Bekk smoothness tester.	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 to the surface being printed, *for example in the gravure printing process,*
Strength	To ensure a good appearance in printing and post-embossing, especially when using tacky inks such as offset lithographic. IGT pick and printability test simulates and checks any defect surface either a surface pick or blister.	Ink, varnish or paper surface may blister if the value of surface strength doesn't adapt to sticky.
Cleanliness	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.	spots (HICKIES) in solid print, loss of definition in halftone illustrations, ink spots in non-printing areas, etc

pH	a surface pH of around 6–8 is preferred for oil-based inks which dry by oxidation. This range is also important for papers or paperboard printed with metal pigments such as bronze and those required for laminating with aluminium foil.	If a surface pH of 5 or less is unsatisfactory, it can lead to poor ink drying, corrosion on metallised paper.
Tension & energy	Surface treatment allows ink can spread and absorb more easily on printed surfaces without reticulating. To increase surface energy, it is done by surface oxidation using an electric corona discharge or a gas flame and checked by using Dyne measuring pens.	The wetting angle of ink on paper or polymer film surface.
Structure	Visual assessment via observing the surface under low-angle illumination which highlights any irregularities in the surface. 	The appearance varies depending on the direction, i.e. MD or CD, of observation and illumination.

3. Gloss

The gloss is measured at an angle of 75o, and printed and varnished surfaces are measured at 60o. 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.



Principle of gloss measurement for paper and paperboard

4. Opacity

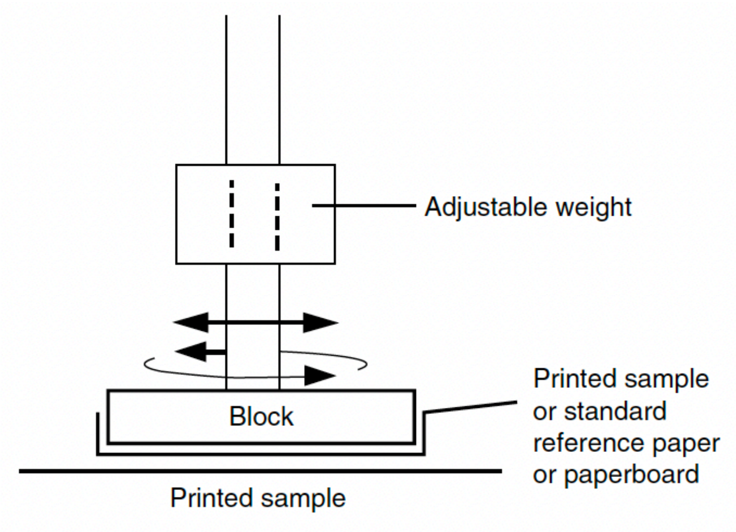
Opacity relates to the capacity of a sheet to obscure print on an underlying sheet or on the reverse of the sheet itself. it allows printed images to show clearly and sharply on one side. Opacity is measured by comparing light reflectance, using a spectrophotometer, from the surface of a single sheet over a black background with the reflectance from a pile of 100 sheets of the same grade.

5. Ink and varnish absorption and drying

To determine setting time in which printing and varnish have the enough period of time to absorb into substrate and drying or cross-linked. To determine the setting time for printing inks and varnishes, sufficient time must be allowed to penetrate the substrate and dry or cross-link with the paper surface. It also refers to selecting suitable inks and printing techniques for each paper types.

6. Rub resistance

To determine the strength of the fibre layers in the paper structure. It also tests the scratch resistance and bonding of ink and varnish with paper once information and images are printed on a paper surface and the effect of moisture during printing and finish.



Reference materials.

[1] *Packaging technology – Fundamentals, materials and processes. 2nd edition*. Edited by Anne Emblem and Henry Emblem (2012), Woodhead Publishing.

[2] *Food and Beverage Packaging Technology 2nd edition.* Edited by Richard Coles & Mark Kirwan (2011), Blackwell Publishing.

[3] *Handbook of Paper and Paperboard Packaging Technology 2nd edition.* Edited by Mark Kirwan (2013), Willey-Blackwell Publishing.