Material Design and Technology of Cartonboard Packaging

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Paper Technology
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Tämä työ esittelee kartonkipakkauksien valmistusprosessia aina raaka-aine valinnoista valmistusprosessien kautta viimeisiin jalostusprosessin vaiheisiin. Tavoitteena on kerätä tietoa, jonka avulla voitaisiin tuottaa tehokkaita, ympäristöystävällisiä ja erityisesti toimivia kartonkipakkausratkaisuja.

Tämä työ on julkisesti tarjolla kaikille käytettäväksi viitemateriaalina ja tarjoaa myös mahdollisuuden katsoa tarkempia tietoja alkuperäisteoksista tarjoamalla kaikki käytetyt viitteet. Työ sisältää sekä perustietoja että jonkin verran monimutkaisempia tietoja kartonkipakkauksen ja sen materiaalien valmistusprosesseista.

Tämä kirjallisuuskatsaus on kerätty monenlaisista tieteellisistä materiaaleista, kirjoista ja internetistä, mutta aikaa on käytetty myös tuottamaan helposti ymmärrettäviä taulukoita, joista tiedot on saatavilla helposti ja nopeasti. Tämä työ ei sisällä uusia tai alkuperäisiä mittauksia, mutta antaa vinkkejä mitä näistä tuotteista kannattaa mitata.

Työ tarjoaa tietoa kartongin valmistuksesta ja siinä käytössä olevista muuttujista joilla voidaan vaikuttaa viimeistellyn pakkauksen ominaisuuksiin ja erityisesti sen mahdollisuuksiin jatkojalostuksessa. Tästä voi olla apua sekä pakkausten ja materiaalien valmistajille että asiakkaille, joilla on ongelma ratkaistavana tai jotta jalostaja voi vaatia paremmin tarvitsemiaan ominaisuuksia kartongilta valmistusvaiheessa.

Vuosien 2009-2012 erilaisia trendejä on tulkittu alan erilaisia arvoja mittaavien parametrien avulla, jotta konteksti jossa tämä työ on kirjoitettu tulisi selvemmäksi.

Työssä tarjotaan myös tietoja siitä kuinka erilaisia tuotteita tulisi pakata ja mitkä niiden erityisvaatimukset ovat sekä vertaillaan muita pakkausmateriaaleja kartonkiin.

Työn ulkopuolelle rajattiin aaltopahvit, joita teoriassa voidaan pitää kartonkipakkauksina.

Asiasanat: kartonki pakkaukset suunnittelu ominaisuudet materiaaliteknologia

ABSTRACT

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This thesis explores the different types of cartonboard packages through the whole line of their manufacturing process from choosing the right materials for the board in to final converting processes. Producing efficient, environmentally friendly and most of all right kind of cartonboard package is the core theme in this work.

This work is publicly available and can be used as a reference by anyone who needs to learn the basics and some of the more advanced things of cartonboard packaging. Since the use of cartonboard is trending upwards there clearly is a need for an easily accessed information source like this thesis.

The information in this thesis is collected from variety of literary and internet resources through reading studies and collecting the relevant information under simple paragraphs. This work however does not have any measurements and it is a pure literary review. There are, however, plenty of tables, which collect information in to an easy-to-read format for fast referencing.

Also statistics are included and analyzed on the future and today of cartonboard packaging to provide a context in which this thesis was written.

This thesis also includes information on how to optimize the board making process to suit customer needs. Furthermore the thesis can also be used by manufacturers to help them understand what to ask for from the substrate manufacturer and also includes a short guide in to other packaging materials.

There is also a chapter on how to pack different types of products and what are the demands for these products in order for them to arrive to the final user intact and how to provide extra functions to improve the functionality of existing packaging

Corrugated boards were excluded from the study although some people may consider them a type of cartonboard package.

Key words: cartonboard packaging design material technology properties printing converting

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Index of Abbreviations

SBS	Solid Bleached Sulfate
SUS	Solid Unbleached Sulfate
WLC	White Lined Chipboard
LPB	Liquid Packaging Board
FBB	Folding Box Board
HW	Hard Wood
SW	Soft Wood
DIP	Deinked Pulp
CTMP	Chemithermomechanical Pulp
TMP	Thermomechanical Pulp
(P)GW	(Pressure) Ground Wood
PCC	Precipitated Calcium Carbonate
GCC	Ground Calcium Carbonate
$\mathrm{T{:}O_2}$	Titanium dioxide
PE	Polyethylene
LDPE	Low Density Polyethylene
PET	Polyester or Polyethylene terephthalate
PS	Polystyrene
S/A	Acrylic
PVAc	Polyvinyl Acetate
PP	Polypropylene
EVA	Ethyl Vinyl Acetate
EAA	Ethylene Acrylic Acid
EMA	Ethyl Methyl Acrylate

1. INTRODUCTION

Packaging is a big part of everyday life of people all around the world and it has a long history from leaf wrappings to barrels to modern day plurality of diverse materials and processes to create and customize them for specific needs. Cartonboard is one of these materials and it provides material for many uses in the field of packaging and is the most common of all packaging materials used today and its place in our everyday life seems secure.

Raw materials and their choice in the manufacturing processes are essentials and fillers, coatings and cellulose fibers are a big part of papermaking. In nearly every paper and paperboard grade fillers are found in the furnish and pigment coated cartonboards are a selling point, while extrusion polymers provide a wide variety of functions to benefit the packer and the end users.

Printing, converting and finishing processes are used to improve the overall quality of the cartonboard package and to make the forming of the right kind of package possible. These processes put extra demands for the actual cartonboard in order for the processes to run smoothly enough for mass manufacturing. Some of these properties include the friction coefficients of the surface, smoothness and porosity, but also such things as the ability to form a clean crease. This makes the choice of the right substrate and the substrate quality important and interesting.

The aim of this literary review is to provide a compact and clear package of information on different aspects of cartonboard packages, with information and sources provided for a more deep study in to the material technology of cartonboards. Typical processes and materials are described to provide a wide information source as well as a few more innovative and less established methods and materials. The perspective is on the functions of the material, but also on how to improve a product that is deficient in quality. Different grades are also explored.

Corrugated boards are only briefly explored in the other packaging materials section of this study.

2. BOARD GRADES

There are several different types of board products used for many different types of functions. It is essential to know what your goal is in order to choose the right type of board raw material. Functionality and quality are naturally defined by factors in the production line, but the grades share basic properties by which they are defined. Board grades are usually divided into 3 main groups by their primary material structure. Cartonboards are a group made out of layered single sheet material and are a lot like paper, except they are usually thicker and heavier than paper grades. Different types of cartonboard packages made from various board grades can be seen in figure 1.

Figure 1: Cartonboard packages made out of SUS, SBS, LPB and FBB

Typical grades include liquid packaging board and white lined chipboard. More uses and grades are listed in table 1. Container boards are not used alone, but are combined to produce corrugated board. Two main subcategories are linerboard and corrugating medium, which are combined in to corrugated board. The last category of paperboard is specialty boards, which include a wide variety of different types of boards. The end uses for these products vary, but these boards are not usually used for packaging, if you do not count core boards. (Kiviranta, 2000, p.55)

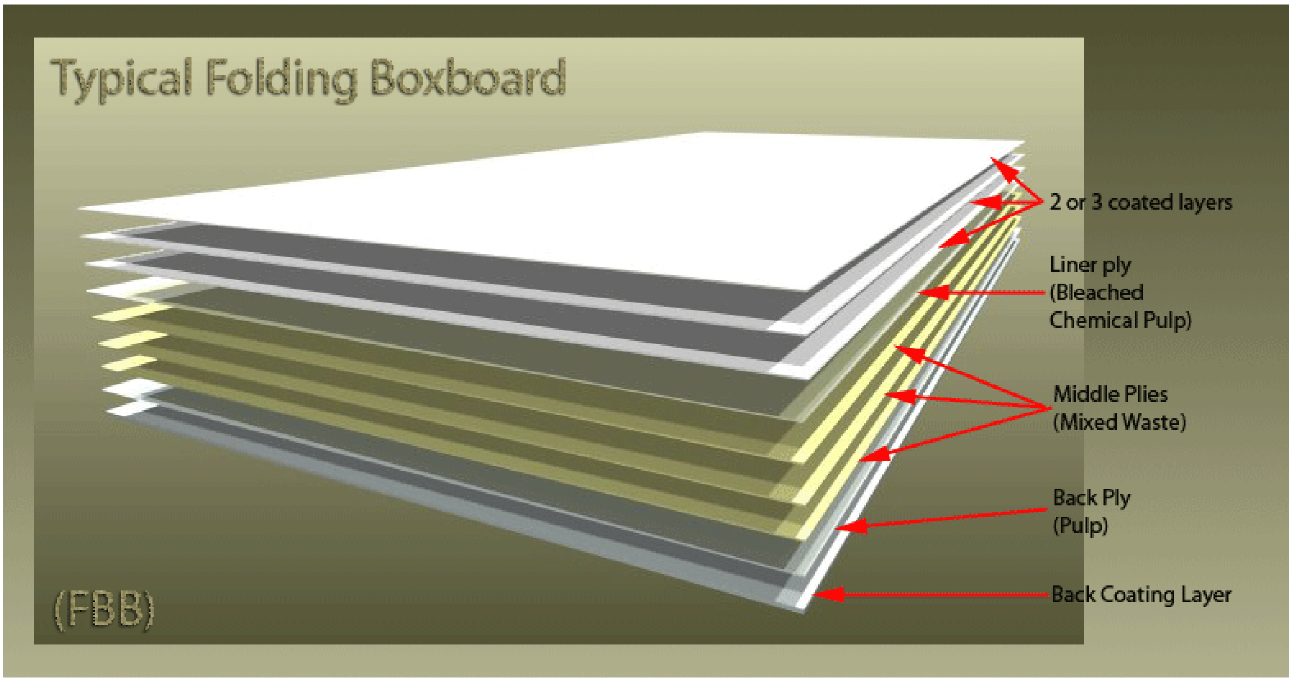
Table 1: Cartonboard grades, typical uses and basis weights (Kiviranta, 2000, pg.55-63; Weyerhouser, 2012 Specifications; Hine, 1999, pg.111)

Grade	Abbreviation	Typical Products	Basis weight g/m^2
Folding Boxboard	FBB	Cosmetics, cigarettes, pharmaceuticals	160-450
White Lined Chipboard	WLC	Non-demanding food packaging	200-450
Solid Bleached Board	SBS	Odor and taint free packaging	180-380
Solid Unbleached Board	SUS	High strength packaging (i.e. beverages)	up to 500
Liquid Packaging Board	LPB	Various liquids, mostly milk and juices	240-450

2.1 Folding Boxboard

Folding Boxboard, sometimes called Scandinavian type FBB, is a versatile packaging material used for many packaging solutions and even for some non-packaging products like book covers or post cards. Like all cartonboards FBB is a layered product and uses different types of pulps in different parts of the layered structure. Outer layer consists of bleached wood-free pulps and the middle ply may be any type of mechanical pulp like TMP or CTMP, so that the final product has the necessary stiffness and bulk. A typical layered structure can be seen in figure 2. Folding Boxboard is a really demanding product. To improve surface properties FBB is usually coated or surface sized. The surface affects printability and friction properties. A sample of a FBB package can be seen in the lower left-hand corner of figure 1. As mentioned before stiffness is important, because it correlates well with stacking strength of the final package. The products packaged in FBB packages usually have also a high demand for purity with no taste or odor contaminants to the packaged product. Typical tests include Scott Bond and IGT. (Kiviranta, 2000, pg.59; Häggblom-Ahnger, 2003, pg.73)

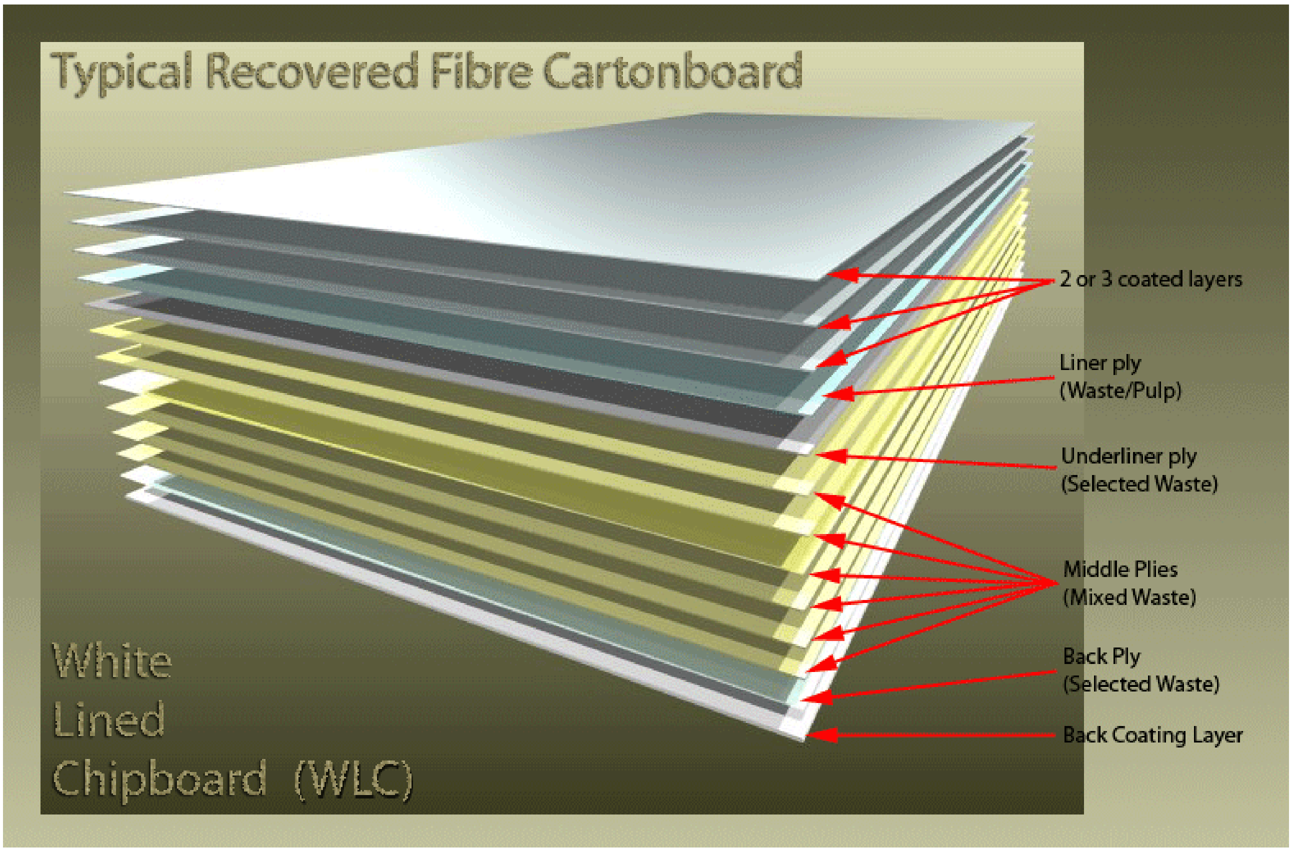
Figure 2: Typical layered structure of FBB with coating layers included (P.Quarry, Box & Carton Materials, 2009)



2.2 White Lined Chipboard

White Lined Chipboard resembles FBB as far as end uses go, but it is used for the less demanding products and in the case of food products it is usually used as secondary packaging with a plastic primary package. WLC is usually made of four layers with the goal to keep costs low, but printability in the top ply good. This leads to a design where there is an extra layer under the top ply called undertop ply. The idea behind this structural property is that low brightness middle ply can be hidden under the undertop ply so that brightness can be improved without using too much of the more expensive top ply material, which is usually bleached pulp. Under top ply is usually made out of the same material as back ply which can be any lower grade pulp, like CTMP or De-inked pulp. Middle ply can be anything cheap like recycled newsprint or mixed waste. This structure can be seen in figure 3. WLC is also coated, because the demands are similar to FBB. WLC has to have higher basis weight in order to compete with FBB, because of the lower bulk and stiffness. (Kiviranta, 2000, pg.60; Häggblom-Ahnger, 2003, pg.73)

Figure 3: Typical structure of white lined chipboard (P.Quarry, Box & Carton Materials, 2009)



2.3 Liquid Packaging Board

Liquid packaging board is a broad definition that includes a variety of cartonboard products, which are used for packaging of liquids, but share a host of properties and demands in common. The amount of plies varies, but the original LPB type cartonboard had only two plies. Today there may even be over 4 plies. The most important factor in LPB is purity and this disqualifies non-woodfree pulps and secondary fibers. To promote barrier properties LPB is always extrusion coated or metalized, but not always pigment coated. Structure of a typical LPB brick type juice box can be seen in figure 4. LPB is typically converted into a gable top or brick type packaging which require somewhat different properties due to the nature of their filling and assembling process. Common important properties include purity and cleanliness as mentioned before, but also stiffness, which can be hard to achieve with chemical pulps, but essential in order to stack the packaged products for transfer and shelving. Printing surface can often be a place for compromise, since most of the LPB packages are printed with flexo, but some brick-type packages may be printed with gravure, which will require high smoothness. (Kiviranta, 2000, pg.62-64; Häggblom-Ahnger, 2003, pg 76)

Figure 4: Structure of a typical LPB package with different layers separated and visible.

2.4 Solid Bleached Board

Solid Bleached Board usually consists completely of bleached chemical pulps or sometimes has a layer of CTMP, but its uses include high quality products that are sensitive to contaminants like cigarettes and chocolate. A major unique property of SBS is that it is sometimes a single ply product (sometimes called solid board), which makes it different from other boards and makes it a little more indistinct from paper, especially the lighter basis weight ones. There is also some SBS made with a three ply machine. The advantage of this is that control of variables in all the plies is possible and thus it is possible to have more control over the properties of the final product as far as bulk, printing and stiffness go. A type of SBS package can be seen in figure 6 and structure in figure 5.

Figure 5: Structure of a typical SBS sheet with coating layers visible (P.Quarry, Box & Carton Materials, 2009)

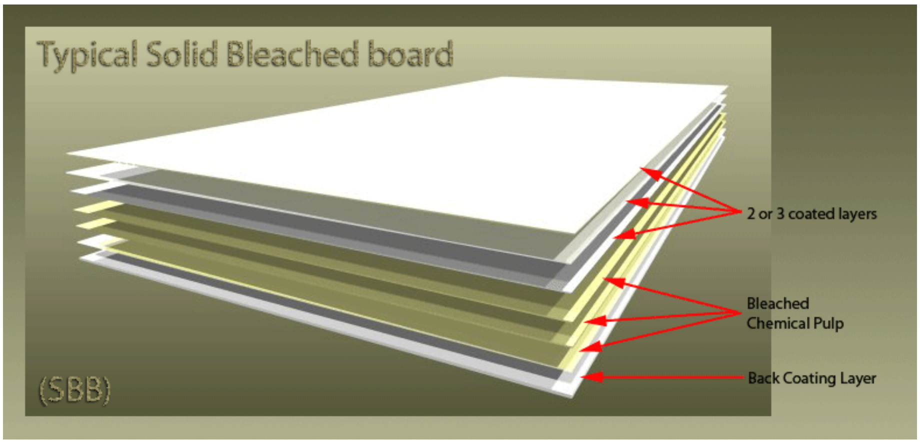


Figure 6: Colored SBS package made for a premium cheese with inner layers visible and foil stamped decorations.

2.5 Solid Unbleached Sulfate

Solid unbleached sulfate board is sometimes also referred to as Coated Natural Kraft (CNK), when produced as a single layer product. Like most cartonboards SUS also comes as a plied product. A typical grade has two or three layers and is coated. Printing properties are of consideration, but the more important qualities are stiffness and strength properties, since SUS packages usually serve as beverage carriers, which need to be able to take stress from heavy products. A beverage carrier is presented in figure 1 on the left side and one with all layers and coating visible in figure 8. Figure 7 has an illustration of the layered structure of SUS. (Kiviranta, 2000, pg.61-62; Häggblom-Ahnger, 2003, pg 73; Stora-Enso packaging guide, pg 13)

Figure 7: Typical structure of a coated SUS product (P.Quarry, Box & Carton Materials, 2009)

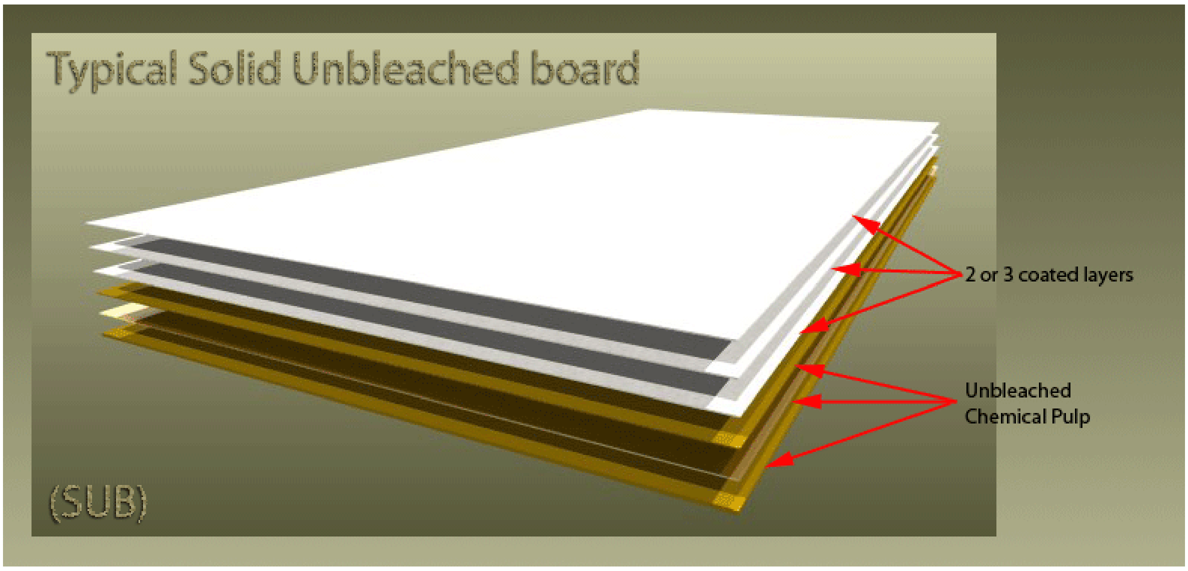


Figure 8: a SUS package that has been torn open to reveal the inner layers, bleached top ply and the layer of coating on top.

3. CARTONBOARD RAW MATERIALS

First and foremost the materials are chosen according to the end use of the cartonboard to fulfill the basic need of the typical products packaged in that type of board. Typically the core elements are included in to the thick middle ply and surface properties are fine tuned with the outer layers. The layered structure of boards makes it possible to use a wide variety of fiber materials, but also affects the use of broke in the machine after the layers have been combined, sized and coated. Price is also affected by the types of pulps used, because of the yields and price of pulp raw materials. Comparison of the fiber raw materials can be seen in table 2.

Table 2: Pulps used in cartonboards and typical qualities of these pulps (Kiviranta, 2000, pg-58-64; Häggblom-Ahnger, 2003, pg.31-36)

Pulp:	Grades:	Qualities:
Bleached HW	FBB, WLC,SBS,LPB	White, doesn't yellow, purity, expensive, low yield, shorter fibers than SW pulp, surface properties good, low stiffness
Unbleached HW	SUS,LPB	Strength, low yield, brownish, short fibers, low stiffness
Bleached SW	FBB,WLC,SBS,LPB	White, doesn't yellow, purity, most expensive, low yield, long fibers, strong, surface properties poor, low stiffness
Unbleached SW	SUS,LPB	Strongest pulp, low yield, brownish, long fibers, low stiffness
CTMP	FBB,WLC,SUS,LPB	High to moderate yield, some impurities, average price, average stiffness, relatively high strength
TMP	FBB	Impurities, short fibers, high stiffness, high yield, cheap
(P)GW	FBB,WLC	Impurities, short fibers, high stiffness, high yield, cheap, low strength, high fraction index
DIP	WLC	Grayish, Impurities, moderate cost, short fibers, average to high stiffness
Broke	FBB, WLC,SBS,SUS,LPB	Mix of materials used in the process.
Old newsprint	WLC	Impurities, cheap, low grade, gray

If the amount of different pulps and fillers is broken down, it is seen that the cartonboard grades have very little in the way of fillers. Some products are even produced without using any fillers, this can be seen in table 3. Typical fillers include fillers from the coated broke, so any of the typical fillers in paper may be present.

Table 3 Pulps and fillers in Cartonboard by amount (Grönfors, 2010, pg.27)

		Mechanical	Chemical		
Grade	Fillers (%)	TMP, PGW (%)	Hardwood (%)	Softwood (%)	DIP (%)
FBB	0-5	60	20	15	0
WLC	0-5	30	20	15	30
SBS	0-5	0	80	20	0
SUS	0-5	0	40	60	may be used
LPB	0-5	0	80	20	0

3.1 Chemical pulps

Chemical pulps are generally split in to two categories; hardwood and softwood pulps. Hardwood pulps are used in the outer layers, because of their effect on surface properties, whereas softwood pulps are needed to get enough strength to the final paperboard product. The problem with using purely chemical pulp is that it is hard to get enough stiffness and that means using mechanical pulps whenever possible in the inner layers. Chemical pulps are also more expensive than mechanical pulps, because of their lower yields in the pulp production. However where chemical pulps are unbeatable is purity. This is especially critical when packaging is going to be used for food or pharmaceuticals packaging. Also chemical pulp provides a very suitable printing surface when coated, because of the inherent whiteness of bleached pulp and even unbleached pulps can be coated with titanium oxide to get a really white and opaque coating layer. Pulps can be produced onsite or bought from the market. (Nordman, 1999, pg.629; Häggblom-Ahnger, 2003, pg.31-32; Karlsson, 2006, pg.88-89; Sepsilva, 1997, pg.16)

3.2 Mechanical pulps

Mechanical pulp differs greatly from chemical pulps. They contain contaminants like lignin, but are very suitable for board production and have been used for a very long time. Due to the layered structure of the multi-ply cartonboards it can usually be used in the middle layers and thus do not compromise the product inside and give qualities that are needed in the final products, like printability. Mechanical pulps provide a major benefit with high stiffness values.

3.3 DIP, Broke and other recycled materials

DIP and broke are reclaimed from the process itself or from people recycling their used paper products and board packaging. Broke is not usually considered recycled per se, but it has to be handled with certain care to avoid mixing it in to the wrong layers, since it may contain contaminants from the different plies. This is why broke is usually used in the middle ply, which is one of the benefits of a multilayered structure. Low-grade recycled materials like newsprint can easily be used in the inner layers so that the contaminants coming with it do not affect the areas where cleaner materials are required. Typical contaminants are inks, coatings and fillers. De-inked fibers tend to be dark in color, they do not absorb water well and they tend to be stiff. (Karlsson, 2006, pg.88-89; Seppälä, 2002, pg.71)

3.4 Fillers

Fillers are generally used to improve surface properties and to save costs by reducing the amount of fibers required, although fillers reduce strength properties and stiffness so they should be used sparingly in cartonboard. There have been positive results in using precipitated calcium carbonate (PCC) in SBS grades. Results have shown improvement in several key attributes. Other fillers used in paper and board production include kaolin, talc, ground calcium carbonate and titanium dioxide ($T{:}O_2$). The benefits of these fillers are listed in table 4. (Grönfors, 2010, pg.9-12; Gill, 2000, pg.12; Häggblom-Ahnger, 2003, pg.38-41)

Table 4: Relative effects of fillers in paper and board products (Grönfors, 2010, pg.9-12; Häggblom-Ahnger, 2003, pg.38-41)

Filler	Whiteness	Brightness	Porosity	Friction	Gloss	Opacity	Smoothness	Special
PCC	++	+++	++	++	++	++	++	Variety
GCC	++	+++	++	++	+	+++	+	Hydrophobic
Kaolin	+	+/++	-	-	+++	++	+++	Cheap
Talc	++	++	-	-	++	++	++	Hydrophilic
T:O_2	+++	+++	+	+	+	+++	+	Expensive
+ good, ++ better, +++ among the best, - bad								

4. BOARD MACHINES AND THEIR EFFECTS ON BOARD PROPERTIES

Board machine affects functional properties of cartonboard greatly. Knowing how the machine affects certain properties is critical and therefore it is important for both the board manufacturer and the converter to understand the variables. It may affect the properties of the carton, which are important in the packaging line, like porosity, surface roughness and friction properties. Board machines in general have multiple wire sections and headboxes, because of the differing layers. This kind of design makes it possible to have distinct layers with different raw materials. (Hine, 1999, pg.167; Sepsilva, 1997, pg.16)

4.1 Refining

Refining is used to improve bonding between the fibers in the web and it is considered one of the most important unit processes in stock preparation and the board machine as a whole. This process includes using mechanical forces to induce fibrillation in the fibers. This process greatly affects some of the very basic properties like formation and basis weight, but also some more important attributes of a package like brightness and strength properties. Properties required in certain layers are listed in table 5. However, structure of cartonboard presents a problem in optimization. With too little refining the bonding between layers and fibers is inadequate, but too much refining will harm the optical properties, stiffness and may unnecessarily increase basis weight. Dewatering will also be affected, which reduces the rate of production. In layered products where the middle layer composes partially or fully of mechanical pulp, refining should be very light since it has an adverse effect on bulk without increasing strength. To improve interlaminar strength and to get better creasing, well refined chemical pulp may be added. In the top and back ply strength and elasticity are important to get good creases and folds, both of these properties are partially the result of refining. To reduce curling the outer layers have to be refined correctly to counteract shrinking when the web is dried. Optimizing the process has to be done individually to acknowledge the differing raw materials, final product and the refining process in use. (Koskenhely, 2007, pg.94; Sepsilva, 1997, pg.16, 34)

Table 5: Properties of cartonboard layers affected by refining (Koskenhely, 2007, pg.94; Sepsilva, 1997, pg.16, 34)

Layer:	Demanded attributes:
Outer layer(s)	Tensile stiffness, good porosity, high opacity and good brightness
Inner layer(s)	Bulk, stiffness, bonding strength

4.2 Web forming and headboxes

Web forming and layering can generally be divided in to three ways of doing it. The first way is to combine the layers in the headbox, which means that when the stock comes out of the nozzle it has already been combined in to the layered product and when it lands on the wire it is formed there. Second way is to have multiple headboxes that spray the layers on each other in turn and the third is forming three separate layers on separate wires and then combining them before the press section. Differences are listed in table 6. Middle layer is usually the heaviest and thickest and requires most dewatering. Many of the primary requirements of cartonboard are decided when the web is formed. Attributes like strength (both MD and CD), stiffness and printability depend heavily on the structure of the formed web. Curling is also affected by the fiber orientation in different directions. (Norman, 2008, pg.218-252; Sepsilva, 1997, pg.64-70)

Table 6: Effects of different types of layering on the process and web combining (Häggblom, 2003, pg.144)

Way of layering	Price	Fiber orientation	Formation adjustment	Mixing of the layers	Bonding strength
Inside the headbox	Cheap	-	-	-	+++
On the wire	Moderate	+	+	+	++
separate wires	Expensive	++	+++	+++	+

As can be seen from table 6, the most versatile way for layering is the most expensive. The obvious positive effect is that the layers will not mix, which means it is very good for products that have significantly inferior middle ply compared to the outer plies. There is, however, the possibility that the bonds between the layers are not strong enough and may delaminate. This is always a compromise between cost and quality. (Norman, 2008, pg.218-252; Häggblom-Ahnger, 2003, pg.144)

There are also waterless, so called dry methods for forming paperboard and paper webs, which rely on binders to hold the web together, but use no water. There is also a compromise, semidry forming, which tries to combine the beneficial effects from the other forming methods. These, however, are rare and only one air-laid paperboard could be found from Sonoco, which produces coasters from air-laid beer mat paperboard. (Kononov, 2008, pg.290; Sonoco, 2012, Coasters)

4.3 Effects of wire section on cartonboard properties

Cartonboards are generally produced using either the traditional fourdrinier method, a hybrid former or a combination of these two. It is more cost effective to dry the outer plies with fourdriniers and the middle ply, which is often thickest, with a hybrid or twin wire former. Wire section affects web forming, which has already been discussed in the previous chapter. Wire section can be used to affect formation and to control one-sidedness. Fourdrinier forming results in a two-sided paperboard which can be desired since only one side may be printed especially when multiple wires are used this is naturally desirable. Gap formers are utilized in other paperboard products because it reduces linting, produces a more uniform product and gives the best formation, but requires the layers to be combined inside the headbox. (Norman, 2008, 252-272; Sepsilva, 1997, pg.72-78; Häggblom-Ahnger, 2003, pg.144-145)

4.4 Wet Pressing

Wet pressing and the press section has formerly been considered the best way to remove large amounts of moisture and reductions in quality have been accepted in order to make the machines run faster. The paradigm has been changing and now reducing loss of bulk and other properties of the paper are better taken in to account. Especially shoe presses and large diameter rolls are utilized in paper board production. They ensure high linear loads without compromising board properties or dewatering. Table 7 shows the effects of wet pressing

Table 7: General quality requirements and the effects of wet pressing in meeting them (Paulapuro, 2008, pg.365)

Requirements	Effect	Requirements	Effect
Good Formation	-	Suitable Porosity	**
Good Smoothness	**	High Compressibility	*
High gloss	*	Suitable Density	**
Low two-sidedness	**	High Stiffness	**
High Strength	*	High Surface strength	*
Low Strength anisotropy	-	High z-strength	*
Good optical properties	*	Good dimensional stability	-

- No significant effect, *fairly significant effect, ** significant effect

Table 7 shows that stiffness can be affected in the press section and this has lead to rapid developments in the press-section technologies to quell fears of reduced core qualities of paperboard products. (Sepsiva, 1997, pg.83-92; Paulapuro, 2008, pg.364-365; Häggblom-Ahnger, 2003, pg.161-162)

4.5 Drying and the drying section

Paperboard is dried similarly to paper grades with a few exceptions. Traditional drying cylinders are used to reduce the moisture content as the name suggest, but a few special drying methods may be used to get additional effects. All attributes that can be controlled with drying are listed in table 8. (Tattari, 2008, pg.212)

Table 8: Effects of drying on cartonboard in different parts of the package converting chain (Tattari, 2008, pg.223-227)

Area of effect		
Converting processes	**Printability**	**Package(strength)**
Moisture	Smoothness	SCT
Profiles	Porosity	RCT
Water absorption	Gloss	Bonding strength
Stretch/Curl		CMT
Porosity		

Condebelt dryers could be used for good surface and even strength properties, but since its invention it has not been used for cartonboards even though it would be suitable. This leads to no actual reference in use today. The Yankee cylinder or machine glazing (MG) dryer is a cylinder with a high diameter used to reduce the need for calendering to get a better surface for printing, because heavy calendering would harm the core properties in cartonboard such as stiffness and bulk. The effect is achieved by having a polished metal surface and a felted nip. The downside for having such a huge cylinder is that it may limit the highest speeds and cannot be used in the widest machines. The effect is replicated in the high speed machines with shoe calenders, metal belt calenders or putting on a triple coat in coating. (Tattari, 2008, pg.223-225)

4.6 Surface sizing

Surface sizing is usually done in the drying section after moisture content is low enough and is used to get better surface properties and sometimes to modify the chemical properties of the board surface. Since most cartonboards are coated surface sizing serves as a pre-treatment for coating. Typical effects associated with surface sizing can be found in table 8. (Lehtinen, 2009, pg.18; Häggblom-Ahnger, 2003, pg.180-181; Sepsilva, 1997, pg.136)

Table 8: Effects of surface sizing in certain parts of the packaging process (Lehtinen, 2009, pg.18; Häggblom-Ahnger, 2003, pg.180-181)

Area of effect		
Converting	**Printability**	**Strength**
Porosity decreased	Picking and linting reduced	Surface strength increased
	Absorption decreased	Bonding strength
		Stiffness

There are two ways of application for the size. Traditional method has been making a pool of size on a nip and taking the web through that. This method has been too slow for the fastest machines so modern machines use a film. Weight of the coat is relatively low. Typical sizes include modified starch, carboxyl methyl cellulose (CMC) and polyvinyl alcohol (PVOH) which are used to improve strength properties and some functional additives. (Lehtinen, 2009, pg.18; Häggblom-Ahnger, 2003, pg.180-181; Sepsilva, 1997, pg.136)

4.7 Wet stack, machine calendering and metal belt calendering

Calendering is a process where surface properties of paperboards are improved at the cost of bulk and related properties. Calendering is used before coating to prepare the surface and afterwards to smoothen out the coating layer. With SBS and SUS grades a special wet stack process is used. In wet stack calendering the surface of the board is watered so that the top fibers are soft in both of the two nips. This improves smoothness, but reduces bulk. Light boards may have runnability problems. (Paulapuro, 2007, pg.61)

Light machine calendering is done to most cartonboard grades and the idea is similar to wet stack, except no water is used, but the latest development in the traditional online calendering is the long nip calendar. Similar to a shoe nips on the press section it gives smoothing results with less loss of bulk than traditional hard or soft roll machine calenders or stacks. (Häggblom-Ahnger, 2003, pg.217)

The most modern way of improving gloss is metal belt calendering, which is used similarly to wet stack, before coating (and as final calender if the board won’t be coated) and is often used to replace MG cylinders in high speed machines. This type of calender creates a good gloss and smoothness without sacrificing too much bulk by creating a long dwell time. Typical reduction in bulk loss is 7-10%. (Tattari, 2009, pg.227-229)

5. CARTONBOARD COATING AND FINISHING

Coating means covering the substrate, in this case cartonboard, with different substances, usually pigments, wax, plastic or a combination of these. Plastic coating is the subject of chapter 6; this chapter will only go through pigment coating. Coating can be done on-line or more usually on a separate coating station in the finishing area of the mill and usually is calendered for a second time afterwards. Other finishing processes include calendering, winding and sheeting. In winding the huge machine rolls are cut in to smaller rolls to be delivered to the customer or to an in-house sheeting plant. Sheeting is a process where rolls are cut in to sheets.

5.1 Coating

After the pre-coating calendering, the web is ready to be coated. Coating pigments are usually the same as the fillers. The varying properties can be found in the fillers section in table 4. Pigment coating is used to get a better printing surface so it is common to coat only one side of the web when coating cartonboards, since it is usually printed only on one side. Sometimes both sides are printed, but one side is usually used for demanding prints and the other for more basic prints on the inside of the package. Sometimes the backside is coated once and the topside may have as many as 3 layers of coating. Once coated cartonboard package can be seen in figure 4. The first layer of coating is sometimes called pre-coating and is used to improve opacity and fill small pores. Second and possible third layer are the final layers that produce the wanted printing and absorption properties. Every mill doing coating has their own recipes for different types of final results. The basic mixture of different types of materials is the same, but the materials used vary. Table 9 has the typical ranges where different components are present in the coating color. (Kouris, 1990, pg.6; Häggblom-Ahnger, 2003, pg.187-189; Lehtinen, 2009, pg.16-19)

Table 9: Components of coating color by volume of dry solids and total amount of dry solids (Lehtinen, 2009, pg.18; Häggblom-Ahnger, 2003, pg.180-181)

Function	Amount (%)	Typical materials
Pigments	75-95	PCC, GCC, Talc, Kaolin
Binders	5-25	Latexes, starch, CMC
Additives	>1	OBA, NaOH, lubricants
Dry solids	30-75	

Latexes are used in the coating color as a binder and as the name suggests they are used to bind the coating color after drying together and to the substrate. Properties of typical binders are listed in table 10. Binders are usually used together and thickeners may be used to modify the rheology. Thickeners may also have the ability to bind and these thickeners are called co-binders. Starch is the most common binder, but it does not have the necessary binding power to work as a binder alone. This means it is usually combined with latexes.

Table 10: Binder's effect on certain properties (Häggblom-Ahnger, 2003, pg.188-189, 198-218; Lawrentz, 2009, pg.191-226)

Binder:	Starch	XSB	S/A	PVAc	PS
Binding	++	++	+	-	+
Surface strength	++	+	+	+	++
Porosity	-	-	+	++	--
Light resistance	+	-	++	-	+
Water resistance	+	+	+	-	+
Hardness	+	-	-	++	-
Blistering resistance	+	-	++	+	+
Smoothness in calendering	+	+	++	+	+++
Creasing	-	+	+	+	+
Odor & other taint	+	+	--	+	-
Cost	++	+	--	++	+
+ positive effect		- negative effect			

As can been seen in Table 10 the most suitable latex for packaging food is Acrylic(S/A) latexes, since there is very few taints and it provides a good printing surface after calendering. Grades where odor resistance is not that important may use polyvinyl acetate (PVAc), because of its considerably lower cost and good glueability. (Lawrentz, 2009, pg.214-215)

There are several different coating technologies as far as the actual application is concerned. What is special in the case of paperboard is that it can survive a lot more forces than paper. Typical methods for coating cartonboards are film coating and blade coating. Film coating is usually used as the first coating layer and it can coat both sides at the same time, but is not suitable for multiple coating layers and is susceptible to orange peel, while blade coater can coat only one side at once, but can facilitate higher speeds and is suitable for coating up to three layers. (Mäkinen, 2009, pg.470; Häggblom-Ahnger, 2003, pg.195-197)

5.2 Final Calendering

Final calendering is done after the coating has been applied and drying is done. The technologies used are hard-nip or soft-nip calenders. Matte grades use lower linear loads and glossier grades use higher loads and may lose more bulk. Typically SBS grades need more calendering than FBB or WLC grades.

5.3 Winding and sheeting

Winding may be the final finishing process done in the paper mill before shipping the product to the customer. Final quality control is usually done at the winder after slitting. Improper winding may influence reel quality by creping, improper reel tensions or dusting. These may cause problems in cartonboard converting. (Airola, 2009, pg.220-225)

In sheeting the reels are cut, as the name implies, to sheets. Traditionally rolls or reels have been the way customers preferred their product, but later development in printing technologies and the need for shorter runs have produced a demand for sheeted cartonboard. Sheet-fed printing machines offer more flexibility and sheet-fed offset machines produce the best quality products with excellent print quality. Sheet-fed FBB products also avoid unwanted curling and cracking. (Hämäläinen, 2009, pg.328)

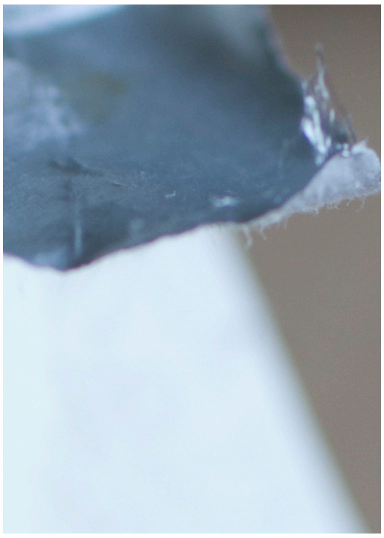
5.4 Dispersion Coating

Dispersion coating is really similar to pigment coating except for its target. While pigment coating has the target of providing a better surface for printing, dispersion coating is applied to create barrier properties. The primary coating material is polymers, like latexes, and primary target is to create a pinhole free coated surface. Secondary targets include gluing and heat sealing. The machinery and application methods are all but the same as pigment coating. Dispersion coated packages are used for e.g. coffee, chocolates and frozen foods. It may also be used as a pre-coating material for extrusion coating. (Kimpimäki, 2008, pg.94-102)

6. CARTONBOARD EXTRUSION COATING

The idea in extrusion coating is to improve the properties of cartonboard by extruding a thin layer of polymers on to the substrate. A polymer layer is visible in figure 9. It has been a very common in liquid packaging boards for a long time, because of their demand for high barrier properties, especially fluid barrier, but is sometimes also used to improve the printing surface or to protect food or other products such as pharmaceuticals. Different polymers can be used to create different barrier properties and even combined with metal foils or other laminated materials to improve other qualities such as strength properties with a laminated mesh. The most important factor in extrusion coating is adhesion. (Karhuketo, 2004, pg.47-48; Crumb, 1999, pg.265; Kuusipalo, 2008, pg .108)

Figure 9: Extrusion coated and foil laminated liquid packaging substrate. The polymer used is PE and the foil is aluminium.



6.1 Extrusion process

Extrusion coating process is relatively simple, but its parameters affect the final outcome greatly. The polymers come as granulates that are basically pure product, with no need for a solvent. These granulates are loaded in to a hopper which assures a constant and sufficient feed in to the extruder. The most important thing at this phase is to avoid water or impurities like small amounts of dirt or other contaminants from entering the process. Typical problems involve condensed water from the air on to the granulate surface. (Karhuketo, 2004, pg.49; Kuusipalo, 2008, pg.108)

Granulates are fed in to a screw which with heat and friction melts granulates into a homogenous mass. This is important later on in the process. The melt is then fed through a screen pack which removes gels, small particles and other similar impurities which would affect the coating quality. The screen pack is fastened to a breaker plate, which is used to make the flow of melt laminar. Next part is the die, which is used to make the final curtain of polymer. There are two types of die, T-die and coat hanger die. The main difference between the two is how neck-in is controlled. Neck-in is the tendency for the curtain to thicken from the edges by contracting towards the center. Neck-in can be controlled by limiting the amount of the melt in the edges and by lowering the die closer to the substrate surface. The second option has the problem of possibly making adhesion to the substrate surface worse, because it is affected by time and temperature. Some polymers are not affected by the air gap. Speed and amount of flow in the curtain define the thickness of the coating. Typical problems in extrusion coating include really small holes, pinholes, curling and unwanted odors and tastes.

6.2 Substrate pretreatments

To assure good adhesion there are several methods of pretreatment. Cartonboard surface is not suitable for good adhesion as it is, since it is characterized by low surface energy, incompatibility and chemical inertness. This has lead to development of varying pretreatments before extrusion coating. If possible, the substrate should be warmed to room temperature before any converting process is applied, because it prevents temperature from affecting the lamination and coating processes. Sometimes further warming at the extrusion coater may come in to question to improve adhesion. It is usually useful to moisturize the board before running it through the machine. This roughens the surface and affects adhesion positively, but also combats curling. This can be achieved with several methods including spraying or steam. (Karhuketo, 2004, pg.34-36; Tuominen, 2008, pg.42)

Chemical primers are used frequently to prime glossy or otherwise hard surfaces to coat. Primer rolls are similar to gravure printing cylinders, a roll with cells picks up the primer solution and it is applied to the substrate to improve adhesion in the laminator nip after the polymer is introduced. Some gravure primers have also been used to create one color images or logos to the surface to be extrusion coated. Other application methods are also available. Typical primers used are acrylic acidic polymers and polyurethane. (Crumb, 1999, pg.266-267; Tuominen, 2008, pg.48)

Besides chemical primers there are also ways of physically treat the board surface to get the surface prepared for extrusion coating. These methods increase the surface energy of the board. In flame treatment the board surface is exposed to, as the name suggests, a flame, which oxidizes a layer on the board surface. It also inflicts micro roughening and removes possible contaminants from the board surface, while also warms up the board surface. All these factors affect adhesion. Alternatives to flame treatment are corona treatment and plasma treatment. Corona treatment works very similarly to flame treatment, except that pure electricity is used and it can also be used as after treatment. Overuse of corona treatment should be avoided because it may have adverse effects such as adhesion failure and damage to the substrate. Corona treatment may also improve printing properties. Corona and flame treatments may be combined for the best possible result. Plasma is the latest method in treating the substrate surface to improve adhesion and several other attributes like bondability, wetting, biocompatibility and printability. The wide variety of results is available because different gasses may be combined to alter the reactions. Oxygen based mixtures are, for example, really effective at adhering polyethylene (PE) to paperboard. (Karhuketo, 2004, pg.37-38; Tuominen, 2008, pg.45-47)

6.3 Co-extrusion

Co-extrusion is like normal extrusion coating except that it uses two or more polymers. It also requires separate screws to produce the melts to be combined, but the amount of layers may be more than the amount of extruders. Typical composition has 3 extruders. The main benefits of co-extrusion are creating multilayer structures which makes saving more expensive polymers or putting protective layers on certain polymers that are sensitive to fluids. Adhesion can also be better because of the higher temperature. Layered structure also prevents pinholes from forming. As far as packaging goes a great advantage is that heat sealing ability may be better customized with layers or by choosing the skin polymer carefully. Combining the layers may prove hard, but then glue layers may be used. Typical problems include waviness of the polymer interface, called interfacial instability and layer non-uniformity where less viscous polymer flows in to high shear areas. (Kuusipalo, 2008, pg.114-116; Crumb, 1999, pg.280-281)

6.4 Lamination

Lamination is a process where two or more materials are combined in to one layered product. In cartonboard packaging the most typical lamination process is to laminate aluminum foil to the surface of the cartonboard. Aluminium laminated substrate is visible in figure 5. This is usually done to juice boxes and aseptic brick type packaging to improve gas and light barrier. This is not unproblematic, since not all materials want to adhere to each other and there may even be differences in heat expansion properties, which has lead to the development of different lamination methods. Lamination can also be used to laminate plastic films on to the board, but the benefits of this type of lamination may also be achieved by extrusion coating. (Karhuketo, 2004, 52-53; Kuusipalo, 2008, pg.188)

Several methods can be used for lamination and they have some benefits and disadvantages compared to each other. Hot melts and waxes may be used when heat resistance is not important. They are usually used for adhesion, but may also provide barrier properties if used in thicker coat weights. Waxes and hot melts are most used in aluminum foil lamination. Extrusion lamination is like extrusion coating, except that it uses the polymer layer to laminate two materials together. If one of the materials laminated is porous, wet lamination can be used. This is a typical lamination method in cartonboard converting. Different lamination adhesives may be used in this method for different results. These can be seen in Table 11. The last method is dry lamination. It is similar to wet lamination except that the adhesive is dried before lamination. (Karhuketo, 2004, pg.191-195)

Table 11: Advantages and disadvantages of some wet lamination adhesives (Kuusipalo, 2008, pg.193-194)

	Advantages	Disadvantages
Sodium silicate	Low cost, good availability, good wetting, good adhesion to aluminium foil and good heat resistance	limited bonding strength and poor water resistance
Casein	Good and flexible bonding to aluminium foil	Corrodes aluminium and degrades relatively quickly
Starch	Cheap, good heat resistance and good adhesion	Hydrophilic and short shelf-life
Latex	Grease proof and good adhesion to most substrates	water resistance and heat resistance

6.5 Comparison of Extrusion Coating Polymers

A lot of thought should be put to choosing the extrusion polymers. Certain polymers have been used for years, while some are relative new comers. All polymers share certain properties that affect the final attributes when used as a packaging material. Some of these effects are listed in table 12. It should be noted that this is a simplified version of polymer chemistry. (Bezigian, 1999, pg.186)

Table 12: Short and simplified effects of polymer's molecular properties to certain properties of a plastic sheet or coating. (Bezigian, 1999, pg.185-191)

	Polymer's molecular properties			
Affected attribute	Molecular weight	Molecular weight density	Density	Chain branching
Impact strength	+	0	0	+
Tensile strength	+	0	+	-
Film tear strength	+	0	0	+
Crack resistance	+	-	0	+
Chemical resistance	+	0	+	-
Heat seal range	+	+	-	+
Brittleness	-	+	0	0
Hot tack strength	+	0	0	0
Brittleness temp.	-	0	0	-
Haze	0	+	0	0
Gloss	0	-	0	0
Other strength properties	0	-	0	0
Melt index	-	-	0	0
Crystallinity	0	0	+	-
Stiffness	0	0	+	-
Tear strength	0	0	-	0
Permeability	0	0	-	+
Curl	0	0	0	-
+ Increased	- Decreased	0 No effect		

There are several common polymers used in extrusion coating and lamination. The most common is LDPE or low density polyethylene. It has been used as long as extrusion coating has been in use, since it is the first polymer used in extrusion coating. It is still widely used and available and especially liquid packaging has benefited greatly, because of its good inertness. To adjust PE properties it has branched in to two other polymers MDPE and HDPE which have alternative properties. MDPE is a compromise between HDPE and LDPE. The properties of LDPE and HDPE are listed in table 13 and layer of finished extrusion coated PE can be seen in figure 5. Ethyl vinyl acetate (EVA), ethylene acrylic acid (EAA) and Ethyl methyl acrylic acid (EMA) are considered co-polymers and are rarely used alone and are usually used in co-extrusion like the name suggest. They can boost certain properties when they are needed for some extra cost. Ionomers are co-polymers too, but they have been relatively rare, because they used to have only one manufacturer. Ionomers are mainly used with aluminium foil, because of its ability to bind well with it. It should be used with other polymers however because of its susceptibility to liquids. Polypropylene (PP) is hard to process, but it provides excellent heat resistance and is thus well-suited for packaging, that is put in to microwave ovens. It is quickly becoming the most used plastic, but is has been in very little use in cartonboard converting, because its potential benefits have not been critical. Polyesters (PET) are also used where high temperature resistance is required. PET is really sensitive to moisture and moisture barrier is relatively low compared to other polymers. (Karhuketo, 2004, pg.65-71; Bezigian, 1999, pg.186-191; Kuusipalo, 2008, pg.143-146)

Table 13: Comparison of common extrusion coating polymers (Bezigian, 1999, pg.192-199)

	LDPE	LLDPE	HDPE	EVA	EAA	EMA	Ionomer	PP	PET
Moisture barrier	++	++	+++	+	+	+	++	+++	-
Gas barrier	+	+	++	-	+	-	+	+	++
Strength	+	++	-	++	++	++	+	++	++
Heat sealing	++	+	-	+++	++	++	+++	+	-
Cost	-	+	+	++	++	++	+++	+	++
Availability	+++	-	+	+	+	+	-	++	+
Adhesion to board	-	+	+	+	++	+	+	-	-
Clarity	++	-	++	+	+	+	-	++	+
Hot tack	-	++	-	-	+++	-	+++	+	+
Seal strength	+	+	++	+++	++	++	++	++	+
Crack resistance	+	++	+	++	++	++	-	+	+
Sealing temp.	+	+	++	-	-	-	+	+++	++
Foil bond	++	++	+	+	+++	+	+++	+	+
Grease resistance	+	+	++	++	++	++	+++	++	++
Abrasion resistance	-	-	+	+	+	+	++	+	+
Chemical resistance	+	-	+	+	-	+	-	++	+
Temperature resistance	+	+	++	-	+	++	+	+++	+++

Latest arrival to the extrusion coating polymer library are biodegradable and non-oil based materials. They are still lacking in their properties compared to the oil based plastics, but are gaining ground, because of the demand for more sustainable packaging. The costs are higher, because production rates are low and cost of raw materials are high. Processing parameters are critical; if they are not met correctly result may be a brittle coating. (Ketonen, 2011, pg.19)

7. PACKAGE PRINTING

The advent of the modern colorful printed package coincides with the beginning of the self-service store era. This is not a coincidence since modern package performs more than one duty. It contains the product, but also serves to sell itself. Printing is the main way to make a cartonboard package eye-catching and one of the main benefits of cartonboard is that it provides a good and easy-to-print surface. There are many methods used for printing, but only 4 are widely used with packaging. Screen printing is sometimes used for special effects and there is nothing to prevent combining of digital methods into other processes for some parts that need more customization. Packaging is always printed before further conversion processes. Different printing methods require different properties from the printed substrate, which can be seen in table 13. Lacquering is usually done at the printing machine, but is discussed further in chapter 8. Often in package printing spot colors are also used instead of the standard CMYK color to produce a brand-specific look. (Lahti, 2008, pg.244-245; Karhuketo, 2004, pg.82)

Table 14: Requirements of the substrate in different printing methods (Karhuketo, 2004, pg.91-143)

	Offset	Offset (sheet)	Gravure	Flexo	Digital
Surface strength	+++	+++	0	+	0
Smoothness	++	++	+++	-/+	+
Surface softness	0	0	++	0	0
Dimensional stability	++	++	+	+	+/-
No curling	0	++	0	0	+
Ink absorption	+	+	++	++	+/-
Electrostatic qualities	-	-	+	-	++

7.1 Offset

Offset printing is the most used printing method in the world. It uses a plate with image and non-image areas separated by hydrophobic and hydrophilic areas. This means that there are heavy demands on the cartonboard dimensional stability, because water may end up on the printed surface.

This is especially important in the sheet-fed machines, because curling will surely inflict misregister, since there are no draws. The main difference with sheet-fed and web-offset is that the former provides better print quality at the cost of production capability, possibly the best of all the printing methods. Sheet-fed offset process can also facilitate different size sheets and has relatively low start-up costs. If the print run length is longer, web-offset processes will be more cost effective. To this day sheet-fed remains the most used in cartonboard printing. Because of the sticky nature of the printing inks in offset, surface strength is a critical property. Linting is a typical problem if this demand is not met. Also too impermeable coating may cause blistering when the inks are dried. (Lahti, 2008, pg.245; Karhuketo, 2004, pg.91-106; Twede, 2005, pg.306-310)

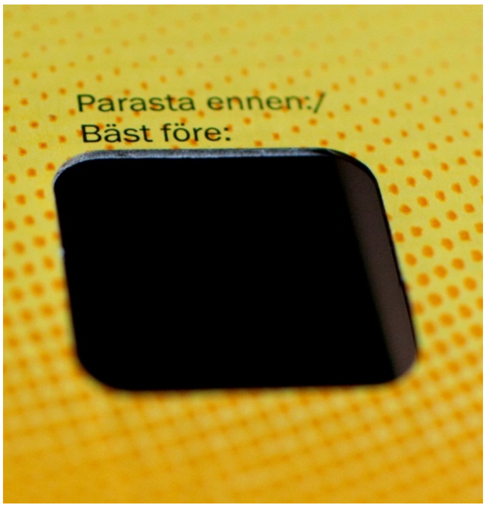
7.2 Gravure

Gravure is only suitable for very long runs, because of the high cost of the printing cylinders. It has found its way in to printing, mostly on high volume cartons that require good quality, like tobacco, because the cylinders may be saved for the next run. Gravure can use a relatively high range of inks, which can be used for great tonal ranges and glossy prints, and has found its place especially in metallic inks. Gravure may also be sheet-fed. In gravure the ink is moved from the engraved pits of the cylinder on to the substrate. This puts demands on the surface of the cartonboard printed this way, especially putting smoothness as a critical property, but a soft printing surface will improve the print quality too. Sometimes electrostatic agents are used to improve the ink removal from the pits. (Twede, 2005, pg.310-311; Lahti, 2008, pg.245; Karhuketo, 2004, pg.107)

7.3 Flexo

Flexo is related to the oldest printing method, letter press, because they both use relief areas to print. The actual flexo method is not that old and has been catching up to gravure and offset. In flexo printing the printed surface is not critical, which has lead to its modern day success in package printing, especially with corrugated packaging which can be seen in figure 10. It may easily print coated or uncoated surfaces, but better surface qualities correlate with better printed image. Sheet-fed flexo machines are rare but they do exist. Even though flexo print quality has been improving it is still used mainly for low-quality products with few colors, like milk cartons. (Lahti, 2008, pg.246; Karhuketo, 2004, pg.116-117; Twede, 2005, pg.304)

Figure 10: Flexo printed corrugated board beverage carrier with a window to see date of expiration



7.4 Digital methods

Digital method is an umbrella term for several different types of printing, which are sometimes also called non-contact methods or plateless methods. The two most common of these are methods are electrophotography and ink jet printing, that have steadily been climbing in use mainly due to their ability to produce just-in-time (JIT) patches and their improved ability to produce high quality print. Inkjet produces great quality if the substrate properties are right and demands a good smooth surface with very little ink absorption and some electrostatic properties. Electrophotography is also dependent on the paper’s electrostatic properties and requires some smoothness, but has the benefit that has generally faster production speed. (Lahti, 2008, pg.246; Twede, 2006, pg.312; Hine, 1999, pg.150-151)

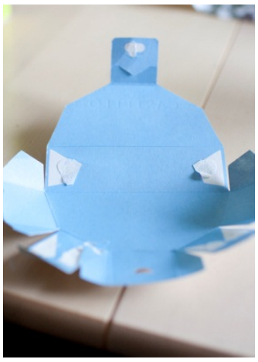
8. CONVERTING PROCESSES

Printing does not have much effect on functional properties of packaging besides creating the colorful exterior. Final conversion processes take care of the functional properties so that the package may be created and filled at the packaging line. Creasing makes the package premade beginning for folds, cutting cuts of the package in to the right blank shape and skiving is used to enable efficient folding. Lacquering is used to make the print more glossy, foil blocking to create metallic decorations and embossing to create areas that are higher than the plane around it. Sealing and gluing are some of the final preparations and they create the ready-to-ship carton.

8.1 Die-cutting and Creasing

Die-cutting uses bladed die or roll to cut through the cartonboard to produce the final shape of the blank. A carton board blank may be seen in figure 11. Due to the nature of the process the board has to have the right properties for a clean cut with no flaking or tearing. Critical properties in cutting include moisture content, dimensional stability, hardness and strength properties. Basically all these affect the cleanliness of the cut, but dimensional stability also affects the processes before and after by getting a well-fitting register.

Figure 11: Cartonboard blank of a cheese package disassembled from a finished and used package



Creasing is a process where hinges are prepared by making small grooves on the blank. This is one of the most critical parts in package converting. Bad creases will crack and there may be additional problems in gluing and erection too if the blank does not fold right. A crease can be seen in figure 8. Die-cutting and creasing are usually done simultaneously in one combined process.

Figure 12: Creasing on a corner of a beverage carrier blank after folding

8.2 Embossing, lacquering, foil blocking and skiving

Embossing is used to make a topographical difference to accentuate a part of the package decoration. The process can also be inverted and is then called debossing. Embossing has very little effect on functional properties and in cartonboard packaging is used for decorations which can be seen in figure 13. The area may be printed or unprinted. For the best results the board should be as thick as possible, but other critical properties include strength, flexibility and moisture. If these properties are not met in either the coating or the base board, cracking may occur making the carton unusable. Demanding designs may also cause problems. (Lahti, 2008, pg.257-258; PPC, 2012, pg.14)

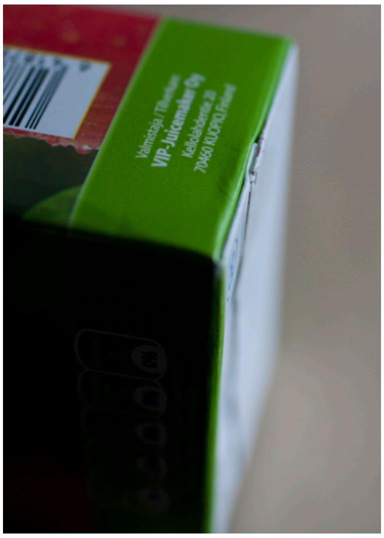
Figure 13: Embossed chocolate package made of SBS where letters are also foil stamped on top of the embossment

Lacquering is used to improve the heat sealability of the package while varnishing is used to improve the prints gloss, but also to protect the carton surface from print rubbing and small surface damage. It may also be used to accentuate certain parts of the print. (Lahti, 2008, pg.249-150; Karhuketo, 2004, pg.62-63)

Foil blocking is applied to create metallic decorations on to the board surface. Foil blocking requires a smooth surface for good adhesion and varnishing may prevent adhesion on to the surface. Embossed and foil blocked decoration can be seen in figure 13 (Lahti, 2008, pg.258-259)

Skiving is a process used to improve folding and barrier ability of the final package. The idea is to remove a portion of the board's thickness from the fifth panel, which folds inside the package, to facilitate the targets. A skived edge can be seen in figure 14. The raw edge that is not coated does not leak after this has been done. Internal bond affects the quality of skiving by preventing unwanted separation of the plies. (Lahti, 2004, pg.259-260)

Figure 14: Bottom of a juice LPB package with a skived fold in the middle



Windowing is used to create transparent areas in to the carton. This may be used by the consumer to see the product before purchasing. Demands for the board are same as in die cutting, since the process is essentially same. There is, however, a need to glue the actual window plastic on to the package, which places some demands on the chemical and adhesion properties of the surface. (PPC, 2012, pg.14-15)

8.3 Sealing and gluing

The blanks are basically unusable by the packer before it is glued, because it cannot be erected or filled since it is only a two dimensional blank. In gluing, depending on the design, one or more seams are glued to create a tube ready to be erected or in the case of set-up boxes ready to be used. This can be done at the packer or more commonly at the carton manufacturer. A glued manufacturer's seal of a corrugated package is presented in figure 15, and is similar in cartonboard packages. Glues have to be chosen according to use. As an example highly sized, coated, varnished or printed may prevent glue from adhering, since they cannot penetrate the surface, this has lead to non-printed area where glue is applied. Runability is the main demand for the material in this process so dimensional stability and friction are important. (Hine, 1999, pg.48-49; Lahti, 2008, pg.270; Twede, 2005, pg.365; PPC, 2012, pg.15)

Figure 15: Manufacturers seam of a corrugated beverage carrier with creasing visible

Heat sealing is used mostly in flexible packaging, but may also be used with plastic coated cartons. This is usually the case with milk and juice cartons, but also food packaging like frozen foods. A heat-sealed gable top juice packaging is shown in figure 16. Heat sealing can sometimes remove the need for gluing in the side seams also, but mostly it is used as the final seam after the package is filled, because the process is relatively cheap and simple. Critical properties of the packaging material to be heat sealed are sealing temperature, seal strength and hot tack. These properties are rarely found in a single polymer, so it is usually a compromise. The seal should be as strong as the package itself. (Lahti, 2008, pg.260-261; Twede, 2005, pg.365)

Figure 16: A heat-sealed and capped gable top juice package with the expiration date print visible

9. TYPES AND TARGETS OF PACKAGING

There are thousands of products and most of them need to be packaged in some way, which creates a demand for very varying attributes in varying kinds of packaging. Generally consumer packaging consists of two types of general packaging types, which are primary and secondary packaging. Primary packaging is in direct contact with the product and secondary packaging contains the primary package. The most common example of such a structure is the breakfast cereals, with a plastic bag inside a WLC folding carton. Typical target for a primary package is to contain and preserve, but it usually does not have to have the best print quality if it is even printed. Secondary packaging serves as a silent salesperson and usually also needs to protect the product when it is in the shelf or stacked and during transport with the help of the bulk container, usually a corrugated box. These are usually called tertiary packaging. Typical board materials and functions of packaging can be found in table 15.

Table 15: Examples of products and their special requirements (Kiviranta, 2008, pg.58)

Product	Special requirements	Typical Cartonboard
Direct Food	Purity, cleanliness, runnability	FBB
Frozen Food	Strength, barrier, purity, cleanliness, runnability	SBS, SUS
Indirect Food	Runnability	WLC
Confectionery	Printability, purity, cleanliness, odor and taint free	FBB, SBS
Beverage carriers	Strength	SUS
Cosmetics	Printability and appearance	FBB, SBS
Tobacco products	Printability, runnability, cleanliness, odor and taint free	FBB, SBS
Pharmaceuticals	Identification, runnability	FBB, WLC
Detergents	Strength, runnability	WLC, SUS
Durables	Strength	WLC
Textiles	Appearance	WLC, FBB
Toys, games	Strength, purity	WLC, SUS
Paper products	Appearance, runnability	WLC
Milk, juices	Runnability, cleanliness, purity and strength	LPB

9.1 Liquid packaging

Cartonboard in liquid packaging is used for juices and dairy products so it has to meet the basic requirements for food packaging, but also has to be able to contain the fluid, which pure cartonboard cannot do. Traditionally this was achieved by wax impregnation, but has lead to liquid packaging being coated or laminated with barrier materials such as extrusion polymers or aluminium foils. Shelf-life is also an important factor in paperboard packaging, especially with dairy products which spoil easily. The board itself consists of pure virgin fibers, because recycled fibers might introduce contaminants to the product even with the coatings. Example of a coated LPB package is shown in figure 5 and a gable top LPB package is shown in figure 12. The package has to endure the packaging process and still look good to the consumer in the store so it has severe demands for its structural properties too. In order for the package not to bulge, and with brick types to be able to be stacked, it has to have stiffness which is almost purely defined by the board and to endure converting and packaging lines it has to have decent mechanical strength properties. Creasability is closely related to the final look of the package as are printing properties. Liquid packages are usually printed with flexo. The package has to be heat sealable quickly since the packaging processes are usually fast. Extrusion coating with PE is the usual solution, because it gives good enough moisture and gas barrier and protects the product from tastes and odors, for gabletob cartons with shorter shelf-lives like milk and fresh squeezed juice. Brick type cartons are usually used for long shelf-life products like juices, juice drinks and UHT dairy products, which employ aluminium foil or a high barrier multiple layer polymer coating for the barrier properties. Gas barrier is important to protect the product inside the package from oxygen, which induces spoilage and destroys both taste and nutrients. Cartonboards and aluminium foils provide good protection against light to light sensitive liquids like milk. (Kuusipalo, 2008, pg.284-338; General Principles of Food Packaging: Packaging Materials, 2004)

9.2 Food packaging

Food packaging is also a demanding form of packaging, because it is controlled by law, much like liquid food products. There are certain demands for purity and chemical inertness of all materials and glues used. Besides the governmental control, also consumer preferences affect the packaging needs, preferences and properties. People prefer to see their food products so windows or transparent packages are preferred, but also there is a demand for convenience especially in processed foods. Examples of this type of packaging can be seen in figures 1, 3 and 7. Depending on the food product packaged it may have to endure severely alternating outside conditions. The product may be packaged still hot and is then frozen to conserve it longer and sometimes the atmosphere in the package has to be controlled to ensure longer shelf-life. Besides these the package has to protect the product inside from contaminants, like dirt and microbes, or light. The packaged food product may also affect shelf-life for many reasons, but as far as material technology of the package goes most important thing is that the package does not affect the product. This means that the outer layer of the coating has to be inert towards the packaged product.

Microbiological contaminants in food products are always a problem since they may produce bad tastes or even make the person who consumes it ill. The best way for protection is to produce an inhospitable environment for microbes inside the package, which requires certain properties from the packaging materials. It involves producing a package that does not puncture and that can hold the modified atmosphere, which basically means that barrier properties have to be adequate and heat sealing has to produce a tight seal quickly enough after the aseptic treatment. If drying is used as a preservation method, then moisture barrier is also important.

Chemical contaminants are mostly gasses that pass through the packaging materials. Basically this means oxygen, which in consort with light may cause chemical changes in the structure of certain food products. Oxygen for example may make fats rancid and thus affect the taste, but also vitamins may be lost. The problem can be avoided with good gas barrier and protection from light. Also modified atmospheres or vacuum packaging is an option.

Physical damage is caused mostly by moisture and is the one that can be affected by the package alone. Hygroscopic foods need protection from moisture with high moisture barrier properties while frozen foods may be damage if moisture barrier is too high, because ice crystals may form inside the package. (Marsh, Food Packaging—Roles, Materials, and Environmental Issues, 2007; Kuusipalo, 2008, pg.284-338; General Principles of Food Packaging: Packaging Materials, 2004)

9.3 Confectionary and tobacco packaging

Confectionary and tobacco are some of the most demanding products packaged in cartonboard. Since these are considered premium products it is essential that no taste or odor contaminants from the package influence the packaged product. Besides that they have to have the best quality of print on the surface and sometimes even on the backside, inside the package, while complying with the needs of food packaging. This means all the materials have to be chosen according to the highest of standards, so these products are usually packaged in coated SBS board. (www.ameft.com, Confectionery packaging trends, 2012)

Figure 17: A premium confectionery package made of SBS and decorated with metallic print and embossing

9.4 Pharmaceuticals packaging

In pharmaceuticals the main demand is for functionality, since pharmaceutical products are sold to need and therefore there is no need for the package to sell it. Depending on the pharmaceutical packaged they may be sensitive to almost anything heat, cold, moisture, light and gases or even contamination by organisms. Like food packaging pharmaceuticals have strict demands for their quality. Especially sterility has to remain from the packaging plant to the consumer. These demands rule cartonboard packages out of primary packaging, but they are used widely as protective secondary packaging to glass ampoules and plastic containers, such as blister packaging. Tamper evidence and protection from children are the latest introductions to pharmaceuticals packaging and these properties are mostly achieved through a combination of material technology (strength properties) and design, which makes it hard for children to accidentally gain access to the products inside. (Kuusipalo, 2008, pg.284-338)

9.5 Electronics packaging

Electronics are becoming more common and this has increased the amount of packaging going for the electronics industry. The main demand is for the package to not accidentally damage the product inside with unintended electrical charges from static electricity produced by friction. This means a primary package that has electro static barrier, static-dissipative materials or static-shielding. Basically these are always plastics with functional properties, but secondary packaging may be strong cartonboards that have moisture barrier, because moisture may influence how well the secondary packaging works. The secondary package also has to protect the possibly fragile electronic device from physical damage, so cartonboards are well suited for the task. (Kuusipalo, 2008, pg.284-338)

10. OTHER PACKAGING MATERIALS

As a packaging material cartonboard does have competition. Cartonboards have to compete with other materials such as glass, metal, plastics and even other products based on wood fibers. Packages may also be combined with other materials as secondary or tertiary packaging to get some or all benefits of both materials. Still paperboard and paper packaging is the biggest segment in the whole of packaging industry. This chapter gathers some of the main competition to cartonboard packages. (Twede, 1999, pg.5-20)

Table 16: Packaging materials for different types of packages and the relative cost of raw materials of the container price (Twede, 1999, pg.5-20)

Form / Material	Trays	Bottle, jar	Can, Drum	Brick	Bulk	Pressure	Bags, sacks	Carded	Tubes	Material cost (%)
Aluminum		x	x	x	x	x			x	->80
Glass		x				x				20-25
Tinplate		x	x	x		x				->75
Cartonboard or corrugated	x		x	x	x		x			50
Paper	x		x	x			x		x	50
Plastics	x	x	x	x	x	x	x	x	x	50->
Flexible laminates			x	x	x		x	x	x	50->

10.1 Other fiber based packaging materials

Paper is thinner than board, but otherwise is produced basically the same way and can facilitate a print quality as good as paperboard or even better. Paper packaging is usually flexible packaging, which can more easily be used as primary packaging for small products and takes less equipment for the packaging line since the package can be made straight out of the printed roll. Paper, however, is less suitable for packaging heavy products or products that need protection from mechanical forces since it is not rigid. Paper is not used for liquid packaging. (Twede, 1999, pg.31-37)

Corrugated board is a combination of corrugated medium and linerboard, which are then glued in to a layered product. Typical corrugated board products can be seen in figure 18. Corrugated board is usually not bleached to conserve strength properties, but if it is, then it is only the back and front liners. Corrugated board is usually coated only if high quality of print is required for a use in consumer packaging. Due to its structure it can withstand a lot of force; especially it can be stacked well, so it is stronger than cartonboard. Smaller corrugations are used for consumer packaging and higher amount of layers and bigger corrugations can be used for more strength needed in distribution packages. Corrugated board does not provide a good printing surface, but is usually good enough for flexo printing and using smaller corrugation can improve printability and reduce waviness. Besides that, corrugated boards are more bulky than cartonboards and thus not preferred for shelving smaller items or consumer packages unless heavy loads have to be carried like in beverage carriers. Heat-sealing for corrugated board is not used. (Twede, 1999, pg.37-44)

Figure 18: Typical cartonboard packages with primary and secondary packages and one distribution package in the back

Molded pulp is not considered as a paper or paperboard product. It has been traditionally used for somewhat fragile products like chicken eggs due to its inherent softness and elasticity compared to other types of packaging. Molded pulp is now also used to reduce the use of Styrofoam in larger cartonboard or corrugated board packages. Molded pulp has limited uses because it has relatively low stiffness and tear strength and is not well suited for printing, because of its rough surface. It has relatively high puncture strength. (Twede, 1999, pg.19-20)

10.2 Metal packaging

Metal packages offer superb properties for packaging as far as functionality goes. It provides great barrier properties against gas, moisture and light and is strong and rigid enough to protect most products and to be stacked. They are also almost tamper proof, because they cannot be reclosed, and offer relatively good printability, if paper etiquettes are used or even if the metal surface is printed itself. Cartonboard's main benefits compared to metal is its lower tooling costs, lower cost of materials, easier transport and it is generally lighter. Metals have a tendency to corrode if they are stored for a long time or if they are exposed to highly acidic products. This may affect taste and odor or possibly even make the product hazardous. Metals are preferred when high pressured liquids or gasses have to be contained. (Twede, 1999, pg.55-65)

Figure 19: A grouping of different kind of primary and secondary metal packages. A metal liquid package is on the right side

10.3 Glass packaging

Glass packages are the main competitor of cartonboard and plastic packages in liquid packaging. Glass packages are inert to chemicals so they can be used to hold acidic and base liquids that would destroy or dissolve other packaging materials. Raw materials for glass packaging are plenty and cheap, but high tooling and difficult transportation raise the price. Fragility is a big problem during transportation, warehousing and retailing. Of all the packaging materials, glass tends to be the heaviest, because strong enough layer have to be used to prevent breakage. Printability of glass is usually poor, so paper labels are widely used. Other benefits for glass are its ability to provide a vintage or premium look widely used in wine bottles, its ability to filter out unwanted light that would spoil the product, easy resealability with a twist-off-twist-on cap and its ability to show the product while it is contained in the package. Glass packaging is especially favoured by alcohol producers, the cosmetics industry and canned food manufacturers. Glass packaging can also be easily recycled.(Twede, 1999, pg.49-53)

Figure 20: Glass packages in various forms. Typical uses include food and beverages

10.4 Plastic packaging

As mentioned before plastic is not a single material but a collection of polymers with varying properties. This makes plastic packages a versatile choice for any packaging need. They are universal as liquid packages which need to have a long shelf-life such as cosmetics, precooked foods and pasteurized drinks. Plastics are so versatile that they can replace any packaging material with the right choice of polymer. Several plastic packages and sleeves can be seen in figure 21.

Figure 21: Different types of plastic packages with pharmaceuticals packaging in the middle

Combined with a backing card they can make a blister package, which can be used for a good looking and almost fully transparent package for a consumer product, while reducing the need for oil-based polymers. This can be seen in figure 22. The main benefit of cartonboard packages over plastics is their environmental impact and a more stable price. Plastic prices are almost universally linked with the price of oil which tends to trend very high compared to wood-based materials. Besides this many environmentally conscious consumers and organizations tend to look negatively towards plastics, which cannot be fully recycled and have a long degradation times. (Twede, 1999, pg.69-74)

Figure 22: A blister package for a toothbrush with a cartonboard backing card

10.5 Obsolete, rare and future packaging possibilities

As the demand for more ecological manufacturing processes and packaging has risen and the conventional materials becoming more expensive than ever before there has been a high demand for new and innovative packaging materials, while old ones are phased out. Traditionally wood was the most important packaging material, but was eventually phased out by the corrugated board package and metal packages, and are now only used to provide a premium or nostalgic image. Wood is very strong, but heavy. Cellophane is a thin plastic-like material, which is made out of dissolved cellulose fibers. It is clear and pure, but has for the most parts been replaced by plastics. It is still sometimes used for premium and gift item packages and for flowers. Biopolymers have similar properties to regular plastics, but they are made from non-oil based raw materials like bacterially fermented sugars. The breakthrough of biopolymers has been hindered by high prices and problems with production capacity. Their main benefits include that they are renewable and may be biodegradable, but lack of suitable additives to improve their often poor heat resistance, weak impact strength and tendency to stick to production equipment. Before the hindrances have been taken care of they'll remain a niche product. Mushrooms have been grown with agricultural waste to form a package and then sterilized and materials such as aluminum have been improved by creating alloys as strong as conventional steel. Fungal material for example is completely biodegradable and consumes less valuable resources than traditional foam packaging. This seems to be a trend in packaging, reducing materials and improving properties. (Twede, 1999, pg. 69; Phys.org, 2012, ‘latest green packaging material’; Zhu, 2010, ‘Nanostructural hierarchy increases the strength of aluminium alloys’; Plastics Technology, Enhancing biopolymers: additives are needed for toughness, heat resistance & processability, 2008)

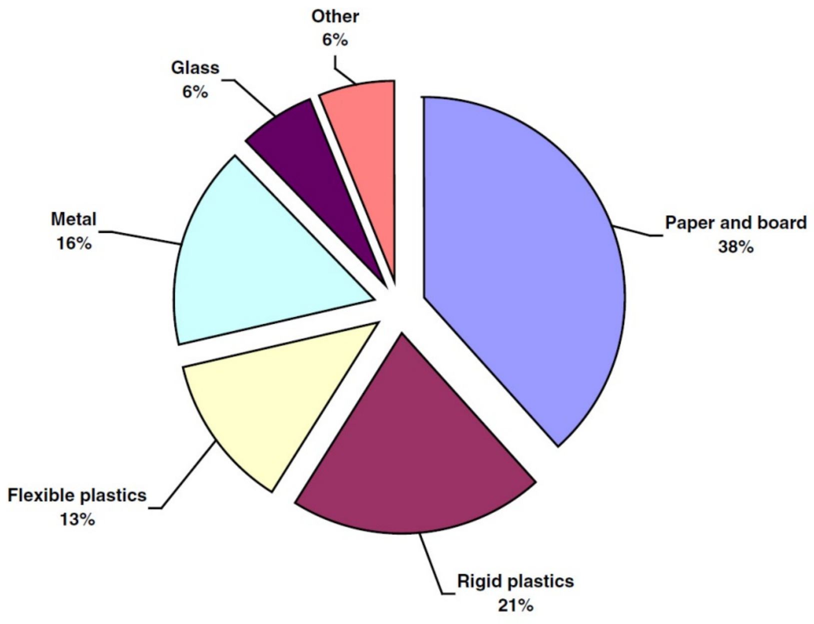
11. TODAY AND TOMORROW OF CARTONBOARD PACKAGING

Packing industry is one of the most stable industries in the world, since the products are universally needed and used. There is however a pressure to improve certain properties of the products so that the customers ever growing needs can be met in a sustainable and economical way. As material technology advances so do the properties and functions of packages. (Packaging-gateway.com, 2011)

11.1 Cartonboard Packaging Today

In the current market, paper and paperboard packaging solutions are the most common, when compared to other packaging materials with plastics coming in a close second. This can be seen in figure 23. Most consumer products use some kind of packaging, so as consumption increases so does the market for packages, especially for fiber-based packages and plastic packages that are so commonplace in the modern society.

Figure 23: Relative shares of different packaging material solutions in 2009 (Pira International, 2010)



The market has been good for board consumption since especially younger people tend to prefer more environmentally sound options, but also because of the adequate structural properties and great possibilities for decorations, but also because of the high use of corrugated board as distribution or bulk packaging material during transport. The next statistic in figure 24 is from 2010 and shows how cartonboard consumption over the early 2000s has changed.

Figure 24: Estimated consumption of cartonboard in Europe (all grades) by year from 2002-2010 (CEPI, 2012)

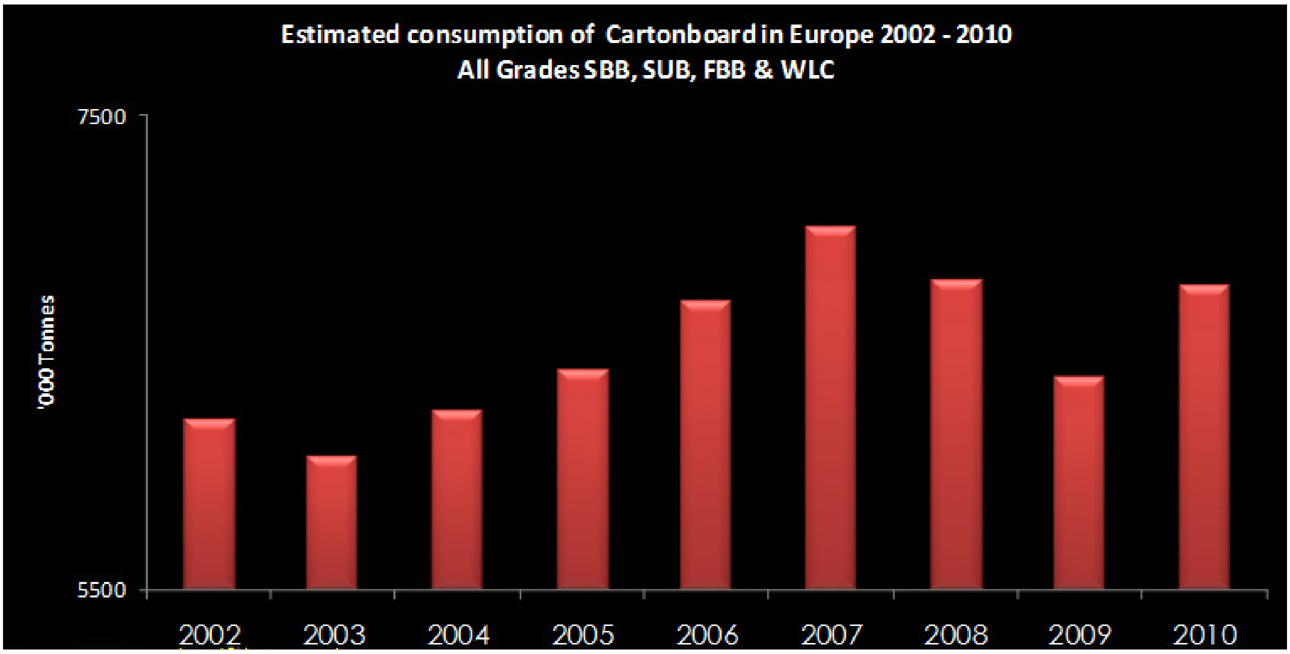
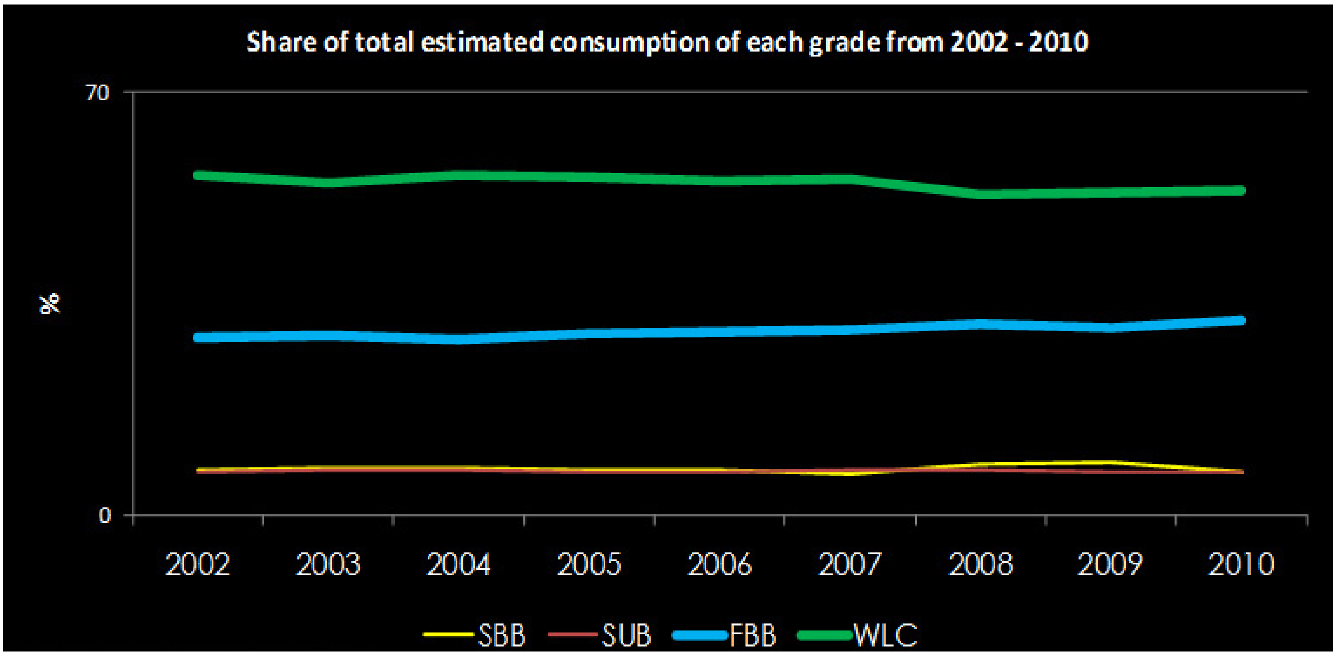


Figure 24 shows that consumption fluctuates somewhat annually, but tends to follow the general trends with the economy. The economic downturn in 2008 is clearly visible as a small dip, but is in general relatively stable, because even if high-end consumer products such as electronics will not sell, food and drink packaging is always needed at pretty stable amounts. CEPI estimates that the reduction of demand for packaging materials from 2010 to 2011 is around 2.0% and 2.5% for the whole fiber-based packaging industry. Figure 25 shows clearly that different packages need different materials.

Figure 25: Consumption of different cartonboard grades by grade from 2002-2010 (CEPI, 2012)



The demand for cartonboard seems stable, but innovations should still be made to improve these products. Cartonboard seems to be a reasonably stable investment and a needed product for the consumers and industry alike. There are, however, certain products, which are affected negatively such as cigarette packages, since in Europe and North America smoking has been declining in both geographical areas. This has somewhat been countered by the emerging markets. (Packaging-gateway.com, Strength under pressure, 2010)

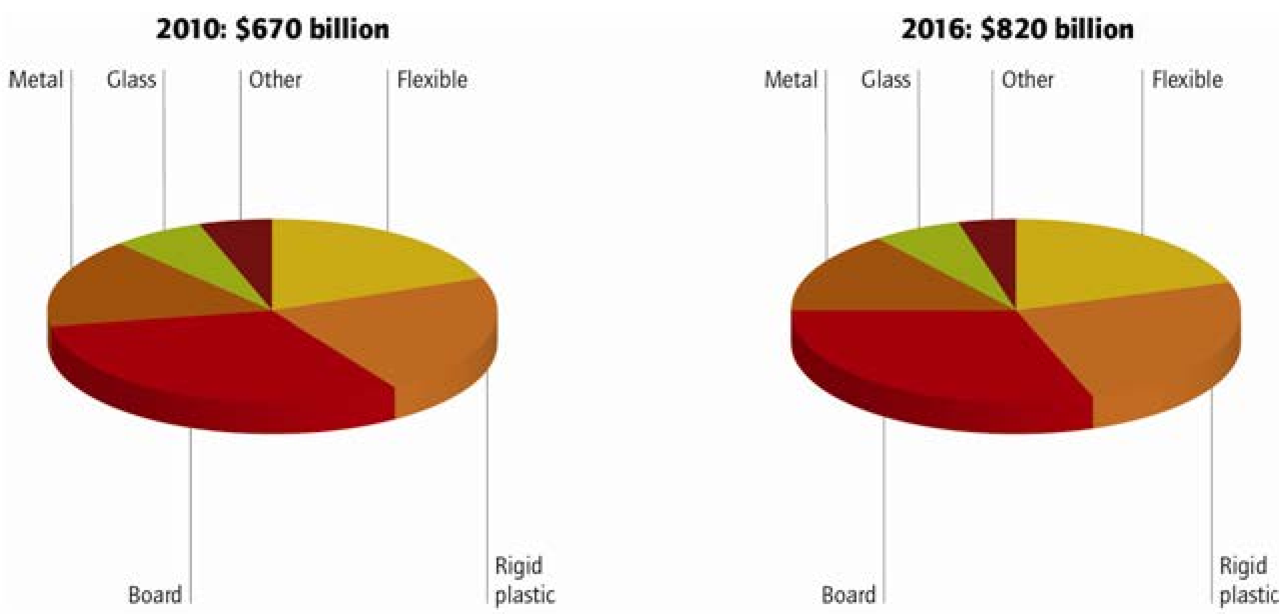
11.2 Future prospects of cartonboard packaging

The future seems to be stable, but the focus seems to be changing. Because products with high volumes have to be in the future produced with lower costs and environmental impact reduction of the materials and energy consumption of the processes will be essential, since it is probable that both will be more expensive in the future. Unlike plastic packaging cartonboard is produced out of renewable resources and is not oil based. This means they will do well if oil prices continue to fluctuate and wood prices remain stable. There has been a trend in reduction of doing more with less by designing same volume packages with less material needed by improving the design and improving the functions of the different materials used. The fiber base of cartonboard is carbon neutral and thus, will have a demand in the future as more taxes and costs are likely to be associated with more pollution and carbon emissions. Some manufacturers are also trying to produce lighter materials to reduce transportation costs.

In the printing part of the package production there will be more need for smaller, even customized, patches so digital methods will probably be the way to achieve this. This will make it possible to reduce dependence on one printer and this will improve the changeover time and ease reliability of deliveries since problem at one plant will not affect all of the package production. Also customizing the package to a certain area may make it more attractive to consumers by offering extra value for the customer. This may also be an important improvement for pharmaceutical packaging since stricter local regulations may have to be met on a short schedule so producing more small patches may actually be economically more efficient.

Emerging and transitional economies will be the key in increasing the demand for packaging in general and this will affect cartonboards. Smithers Pira forecasts that in 2016 the cartonboard packaging sector globally will be worth 250 billion dollars. According to them, major improvements will be done in pharmaceuticals packaging. Also cosmetics will play an important role in the increase. Consumption forecasts are available in figure 26. (packaging-gateway.com, Global packaging industry expected to reach $820 billion by 2016, 2012; packaging-gateway.com, Inkjet Printing market is forecast to reach $67.3 billion by 2017, 2012; Packaging-gateway.com, Strength under pressure, 2010)

Figure 26: Consumption and improvement in the consumption of different packaging from 2010 to 2016 according to Smithers Pira estimates (Smithers Pira Ltd., 2012)



12. CONCLUSIONS

The properties and final quality of a cartonboard package are defined by many different factors. First there is the choice of right materials for the right packaging solution. Then these materials are combined in the board machine to produce the base for the package. The properties of the basic materials can be affected most until this point by choosing the right methods in the board machine. There are usually also finishing processes to improve the wanted properties and to reduce unwanted ones, but also to make the substrate easier to handle in the up-coming converting processes.

The converting processes used vary according to the product that is to be packaged, but in order to create a blank there has to be creasing and cutting, these are the two most basic processes. Other processes include processes customized for a type of package, i.e. skiving for liquid packaging and more generally used processes like extrusion coating to improve the properties to such level that the product can safely be packaged.

Printing is usually used for decorations from very basic prints with few colors to vibrant coloration and even metallic spot inks. Lacquering and embossing are used to make the package more desirable and to create a premium look, while more basic products do not have anything fancy.

Cartonboard has to compete with other packaging materials on the marketplace and this puts pressure on the cartonboard manufacturers to innovate and develop their products to counter their weak points against glass, metal and especially plastics that can be used to produce wide variety of packages.

Consumption of paper and board based packaging materials have remained somewhat stable over the years and they have had the benefit of being by price the most stable product. This will probably also carry board products in to the future, since most plastics are made from non-renewable materials and cartonboard is made out of almost completely recyclable and renewable and especially stably priced materials, which can be used to reduce dependence on oil and oil prices.

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