Tampere University of Applied Sciences
International Pulp and Paper Technology
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Final Thesis

Use of fillers in paper and paperboard grades

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Commissioned by	Nordkalk Corp., Lic.tech. Lars Grönroos

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ABSTRACT

In this work the use of fillers in paper and paperboards grades are examined. The idea was to get to know the concept of fillers and how to use more of them in papermaking. Replacing fibres with fillers is a major theme in this work.

This work was done in order to familiarize the field of paper industry and its uses of fillers. Fillers are used in nearly every paper and paperboard grade. Filler use has increased during the last decades and continues to do so. Fillers bring special properties for paper products that could not be achieved in any other way.

In the beginning of work, fillers and their properties were viewed. These fillers were ground calcium carbonate, kaolin, precipitated calcium carbonate, talc and titanium dioxide, the most common paper fillers. This is followed by the categorization of majority of paper and paperboard grades in the world. The furnish composition of these grades are analyzed and end uses of several grades were evaluated.

Another target of this work was to find out about current paper and paperboard markets. Statistics about paper production and consumption were explored. Data from future projections of paper consumption was examined, too. In these predictions the largest growth of consumption of all paper is located in Asia with China being the most important country. Overview of the markets tells potential grades whose consumption is rising. In the near future paperboards are to be consumed more and more. From paper grades tissue is most likely to see growth.

This paper was done as a background research to find possibilities of increasing filler contents in papers. The base work is to be used in the creation and development of new future fillers.

Keywords Final thesis, fillers, paper markets

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Tekijä	Jarkko Grönfors
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TIIVISTELMÄ

Tämän työn tarkoituksena oli tutustua täyteaineiden käyttöön eri paperi- ja kartonkilajeissa. Työssä keskityttiin täyteaineiden käyttöön ja sen lisäämiseen monella eri paperi- ja kartonkilajeilla. Työn yksi kiinnostavimmista kohteista oli kuidun korvaaminen täyteaineilla.

Työn tavoitteena oli tutustua paperiteollisuuden täyteainekäyttöön. Lähes jokaisen paperi- ja kartonkilajin massaan lisätään täyteainetta. Täyteaine tuo erityisiä ominaisuuksia lopputuotteelle, joita ei muulla tavalla voisi saavuttaa.

Työn alussa keskityttiin täyteaineiden rakenteisiin . Yleisimpien täyteaineiden eli kaoliinin, kalsiumkarbonaattien, talkin ja titaanidioksidin ominaisuuksiin tutustuttiin. Tämän jälkeen paperi- ja kartonkilajit luokiteltiin ja niiden loppukäyttöä arvioitiin.

Työn toisena tavoitteena oli ymmärtää nykyiset paperi- ja kartonkimarkkinat. Tilastotietoja tutkittiin useasta lähteestä jonka mukaan koottiin yleiskatsaus koko markkinoista. Paperinkulutuksen ennusteita tutkittiin myös ja niiden perusteella pääteltiin tulevaisuuden markkinoiden keskittymisiä. Suurin paperinkulutuksen kasvu on Aasiassa, etenkin Kiinassa. Usean kartonkilajin kulutus on nousussa maailmanlaajuisesti. Paperilajeista suurinta kasvua voi odottaa pehmopaperilajeilta.

Työ tehtiin taustatutkimuksena täyteaineiden käytöstä. Ajatuksena oli löytää mahdollisuuksia kasvattaa täyteaineiden määrää paperinvalmistuksessa. Työn tuloksia käytetään uusien täyteaineiden luomisessa ja kehityksessä.

Avainsanat Opinnäytetyö, täyteaineet, paperi- ja kartonkimarkkinat

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List of abbreviations

$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
CEPI	Confederation of European Paper Industries
CO_2	Carbon dioxide
CTMP	Chemi-Thermomechanical pulp
DIP	Deinked pulp
FAO	The Food and Agriculture Organization of the United Nations
FBB	Folding boxboard
FCO	Film coated offset paper
GCC	Ground calcium carbonate
GDP	Gross domestic product
GW	Groundwood pulp
HWC	High weight coated paper
LPB	Liquid packaging board
LWC	Light weight coated paper
MFS	Machine-finished specialties
MWC	Medium weight coated paper
NBSK	Northern bleached softwood kraft
OCC	Old corrugated containers
PCC	Precipitated calcium carbonate
PGW	Pressurized groundwood pulp
SBS	Solid bleached sulfate board
SC	Supercalendered
SUS	Solid unbleached sulfate board
TD	Telephone directory
TiO_2	Titanium dioxide
TMP	Thermo-mechanical pulp
WFC	Woodfree coated
WFU	Woodfree uncoated
WLC	White Lined chipboard

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1 Introduction

Fillers are a big part of papermaking. In nearly every paper and paperboard grade fillers can be found in the furnish. The amounts of fillers vary from none to at least 30% of the whole furnish. They give special properties for paper products that could not be achieved in any other way.

The aim of this final thesis was to get into the world of fillers in papermaking. In this work several different paper and paperboard grades are examined and their furnish compositions are unfolded. Also common fillers and their usage are described. Their properties are evaluated and possible future prospects are contemplated.

The most interesting perspective to this topic was to try to think how the use of long fibre chemical pulp could be replaced by mineral-based pigments, fillers. In addition to the problem on how to add more fillers into the furnish without it losing its beneficial properties, current and future markets for promising paper and paperboard grades were explored.

This paper was also made in order to shine light into the current mineral usage in papermaking. The report is done as a background research for introducing the field of paper industry to a mineral company in order to initiate plotting new markets.

2 Fillers

Fillers are an important part of papermaking. In nearly every paper grade fillers are used. They are used in order to improve certain properties of the final product. The pigments that are primarily used for fillers in paper are kaolin and calcium carbonate.

2.1 Definition of fillers

Paper fillers are pigment powder that is produced mainly from natural minerals. Minerals are combinations of several elements such as e.g. carbon and calcium. The particle sizes of fillers used in papermaking are roughly from 2 µm to 10 µm. Rougher and larger particles are used in fillers compared to the ones that are used in paper coating. Filler particles have also larger particle size distribution. The pigments used in coating tend to be brighter too. These facts divide the pigments to fillers and coating pigments. Fillers are much cheaper than coating pigments.

2.2 Effects of fillers

There are several reasons why fillers are used in papermaking. The main reasons are their low cost compared to fibre and their ability to improve optical properties in the final product. Fillers can also improve surface properties of paper and by that have a positive effect on the printability of the final product. The use of fillers however brings also many challenges in papermaking. Fillers have poor binding capacity which limits their use. Poor binding results in lower strengths in paper. (Alén, 2007; VTT 2009)

Perhaps the most important reason to use fillers is the lower cost compared to fibre raw material. The price of bleached chemical fibre is roughly five to seven times as much as filler prices. Even recycled and deinked pulp (DIP) is more than twice as expensive as common fillers. The great price advantage of filler easily makes a papermaker to think possibilities on how to use more fillers instead of fibres. (VTT 2009)

Fillers improve the optical properties of paper or paperboard in many ways. They improve such properties as opacity, brightness and colour. Opacity is increased because of filler particles scatter light well. Amount of light scattering is dependent on the size and shape of the filler particles, the refraction index of filler and the amount of pigment-air interfaces present in the product. Therefore e.g. very small and flat filler particles are

optimal for obtaining opacity. With the use of fillers brightness and colour of the final product can be controlled. The brightness and colour values of fillers typically beat the values of fibres as most of the fillers are almost 100% white or at least nearly white. (Hagemeyer, 1997; VTT 2009)

Fillers also have a smoothening effect on the paper surface. As small filler particles settle in between of fibres they together form a smooth paper surface. A smooth surface is required for example in rotogravure printing. High use of fillers in rotogravure printed SC-paper might be explained by this theory. Although fillers are needed for a smooth surface and a good printing image, excessive amount of filler will compromise the paper surface strength. The loose particles and fibres will lint during converting and final quality will suffer. (Hagemeyer, 1997; VTT 2009)

2.3 Common fillers

The most common fillers used in papermaking are ground calcium carbonate (GCC), kaolin, precipitated calcium carbonate (PCC). Talc and TiO_2 are commonly used as well. In printing and writing paper GCC and kaolin are both used little less than 40 %. PCC is a paper filler whose popularity is on the rise. Talc and TiO_2 are consumed in quite small quantities and only for special applications. Further details of these fillers are examined below.

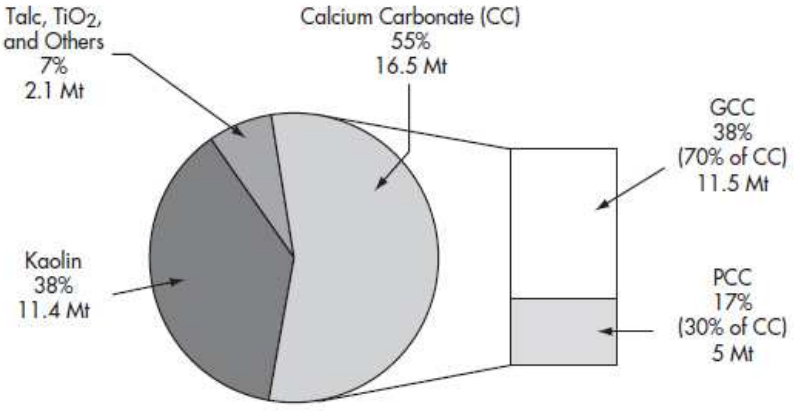

Figure 1: World pigment use in printing and writing papers, 2002 (Wilson)[1]

[1] Original source: Harris, R. 2004. Minerals in paper—looking east for growth. *Industrial Minerals* 443:52–57.

2.3.1 Kaolin

Kaolin clay is a pigment that is commonly used in papermaking. The popularity of kaolin can be explained by its low price, good availability and its relatively white colour.

Kaolin is a natural pigment which can be found from all around the world. The largest deposits are located in the United Kingdom, Central Europe, Brazil and the United States. Small differences in colour, particle size and particle shape can be seen from kaolin recover from different places as seen in Figures 1 and 2. For example, the clay recovered from the United States tends to be finer in particle size. The English kaolin in turn is usually slightly brighter and less yellow. (Alén, 2007; Hagemeyer, 1997)

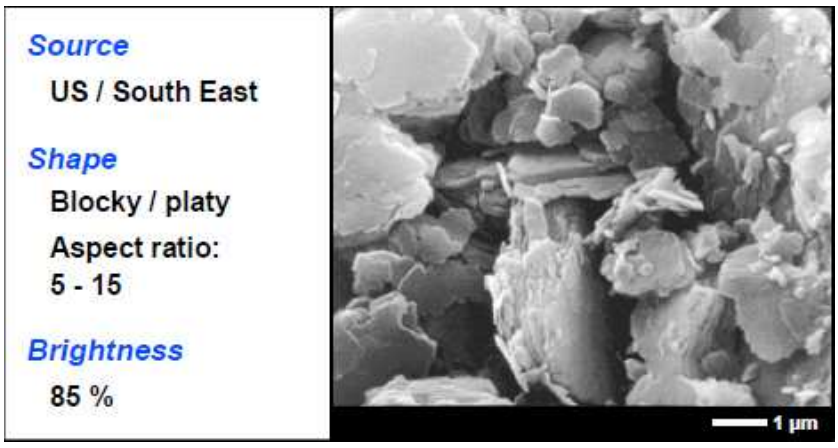

Figure 1: US kaolin (Omya, 1998)

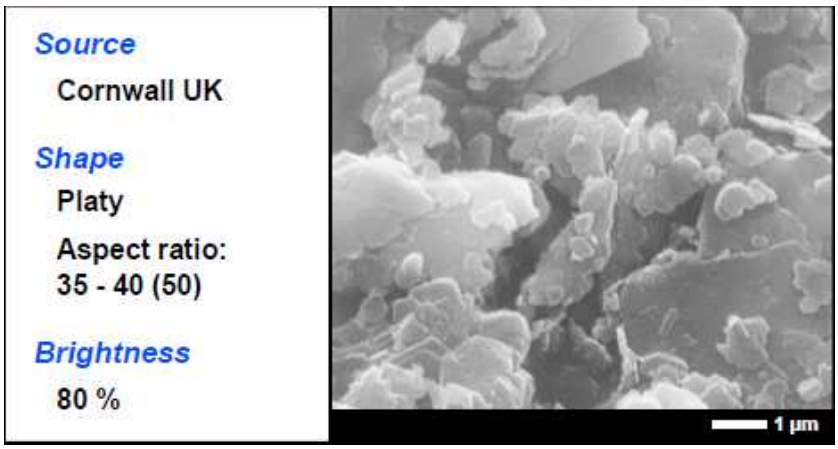

Figure 2: European kaolin (Omya, 1998)

Kaolin as a filler is rather easy to treat and disperse. Little foaming occurs when kaolin is used. Kaolin particles give paper high density which lessens the coating penetration into the base paper. Kaolin is often used in SC paper grades. (VTT, 2009)

2.3.2 Talc

Talc is a good filler for rotogravure printing papers. It is a soft mineral that has flat-like particles to ensure good smoothness. The flatness of particles can be seen in the Figure 3. Therefore it is suitable to be used in paper or paperboard grades that are printed in rotogravure. Talc has been also used to absorb organophilic impurities from the process, such as pitch. Talc has a hydrophobic nature which makes it difficult to produce a water-based dispersion of it. It is also a filler that during processing has tendency to foam. Talc is produced in United States, France and Finland. (Alén, 2007; Hagemeyer, 1997; VTT 2009)

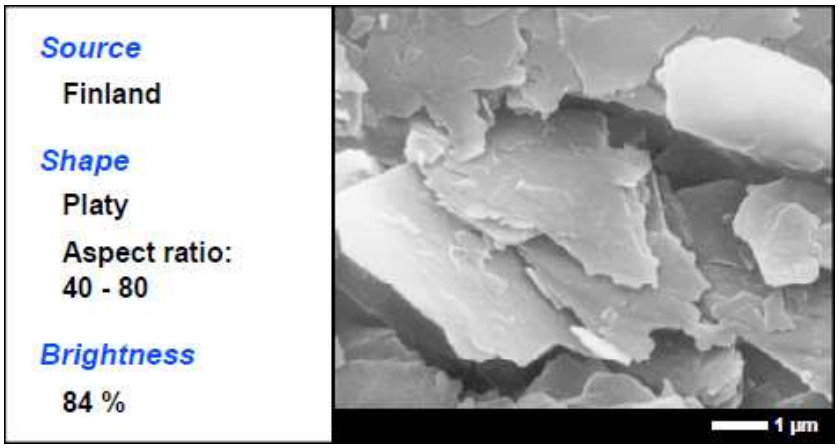

Figure 3: European talc (Omya, 1998)

2.3.3 Ground calcium carbonate (GCC)

In its natural state, calcium carbonate occurs as chalk, limestone and marble. When papermakers use the term "GCC" they are usually referring to ground limestone or marble. Limestone and marble are used because of their high brightness and purity although with chalk the best opacity levels can be obtained. The particle shape of GCC is usually rhombohedral, which creates a porous surface on the paper. GCC is also hydrophobic resulting in releasing water faster. (Alén, 2007; Hagemeyer, 1997; VTT, 2009)

The common use of ground calcium carbonate can be explained by it cheap price and its high brightness. Also the particle shape results in better water drainage than e.g. in kaolin. The rough particle shape creates also challenges. Paper machine clothes, especially wires wear more rapid when GCC is used. (Wilson)

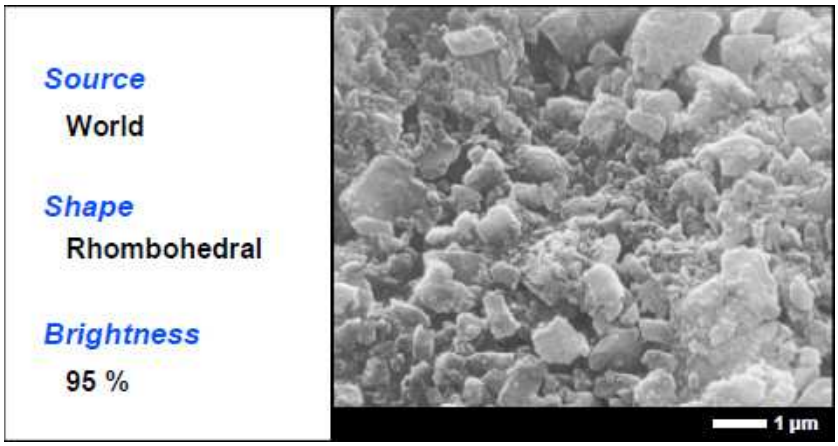

Figure 4: GCC, Marble based (Omya,1998)

2.3.4 Precipitated calcium carbonate (PCC)

Precipitated calcium carbonate (PCC) is a form of $CaCO_3$ which is chemically produced. Its structure is different from the structure of ground calcium carbonate. With the use of PCC we can get better gloss and opacity properties for the paper. The use of precipitated calcium carbonate in paper coating is increasing. (VTT, 2009)

The two main particle forms of PCC are *aragonite* and *calcite*. In aragonite the crystals are usually needle-shaped. These crystals that are also called acicular give the paper glossiness due to their flat appearance. Together with each other they can also create clusters that give higher light scattering. The calcite crystal types are usually produced in rhombohedral(cubic), prismatic(barrel-shaped) and scalenohedral(triangular) form. In rhombic form the crystals give the paper higher light scattering. The prismatic and scalenohedral (Figure 5) crystals are commonly used when high opacity is needed, due to their light scattering efficiency. (Specialty Minerals; Häggblom-Ahnger, 2003)

Figure 5: Scalenohedral PCC (Omya, 1998)

The limestone ($CaCO_3$) is the only material to produce PCC. After the limestone is crushed to small stones of powder it is screened and most of the impurities are removed. The limestone needs to be very pure calcium carbonate to acquire a good yield. After screening the calcium carbonate is heated to 1000 °C in a kiln. This process creates CaO and CO_2. The lime (CaO) is slaked with water in the temperature of 30-50 °C resulting in slaked lime ($Ca(OH)_2$). The slaked lime is combined with carbon dioxide in a carbonator. The temperature can vary from 0°C to 90 °C. The end product is PCC slurry containing mainly $CaCO_3$ and water. Some impurities are removed at this stage also. Although the carbon dioxide is collected from the kiln it is not enough for the process in the carbonator hence additional carbon dioxide is needed. (Eloneva et al. 2005)

2.3.5 Titanium dioxide TiO_2

Titanium dioxide is a pigment that has high optical efficiency. The small particle TiO_2 has very high brightness as seen in the Figure 6. It scatters light well compared to other fillers as shown in the Figure 7. Titanium dioxide is used in such grades that require superior opacity such as lightweight opaque offset papers or bible papers. Show-through is also very well reduced by the use of TiO_2. High price and the abrasiveness of particles restrict broader use of titanium dioxide. (Alén, 2007; Hagemeyer, 1997)

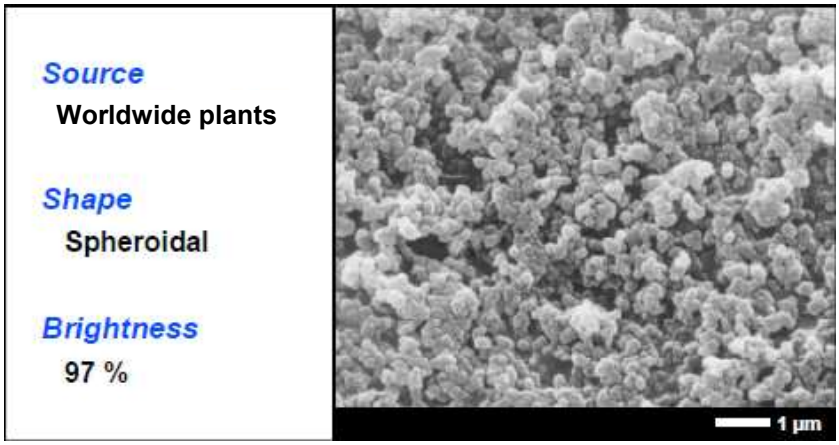

Figure 6: Titanium dioxide (Omya, 1998)

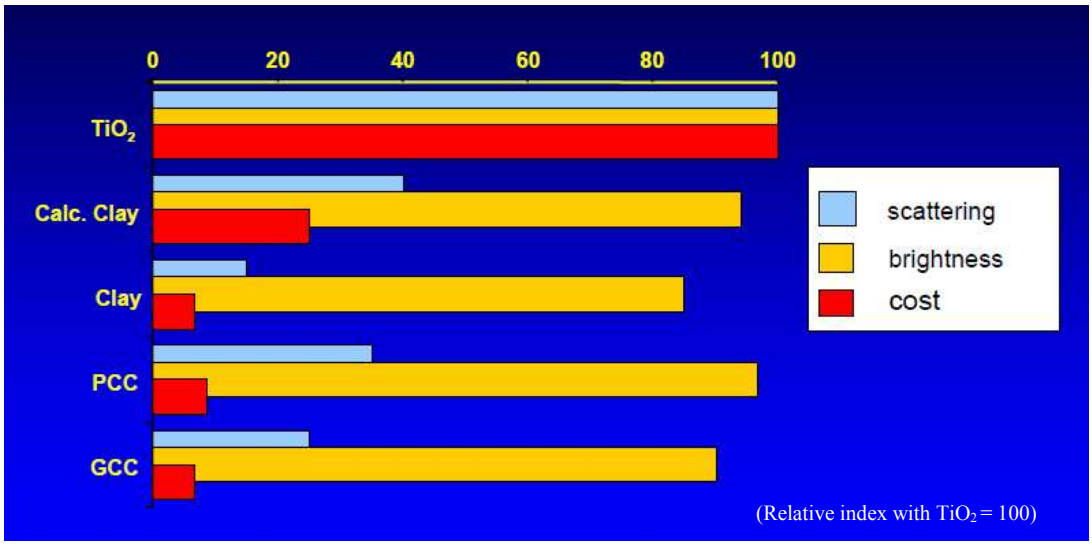

Figure 7: Performance / Cost evaluation – light scattering coefficients, brightness and cost of key pigments (Mueller, 2005)

Each filler pigment has its benefits and disadvantages. In Table 1 properties of the most common filler pigments are compared. The choice of fillers for a specific paper or paperboard grade is usually a combination of different filler types. A paper requiring high opacity with good formation for example would need light scattering TiO_2 particles and small particle PCC as fillers. In table 1 particle size distributions can also be seen. In the following chapter different paper grades and their requirements are discussed.

Table 1: Properties of filler pigments (VTT, 2009)

	Density kg/m3	Particle size % under 2 µm	10 µm	Particle shape
Kaolin	2600	30 - 65	85 - 97	Flat
Talc	2700	10 - 50	60 - 95	Flat
Calcium carbonate - ground - precipitated	 2650 2650	 30 - 90 65 - 95	 95 - 100 98 - 100	 Round Rod-like, round
Titanium dioxide (anatase)	3900		100	Round
Calcinated kaolin	2600	90	100	Aggregated

3 Paper and paperboard grades

Paper and paperboard grades can be categorized in many ways. They can be listed by their furnish composition, production process, end use, printability and other requirements. The geographical location can also be the defining factor in naming and categorizing papers. The classifications used in Europe are different from those used in the United States. The Japanese have a classification of their own too. In this thesis work the European paper grade classification is used. (Paulapuro, 2000)

Paper and paperboards usually are classified by their furnish composition and production process. Mechanical printing papers and woodfree printing papers are the prevailing definition describing papers produced in Europe. These two are divided into specific paper grades (such as LWC and WFC) by their production methods and coat weights. Paperboards category is usually defined by grades that are high in basis weight. This is the most popular way of defining papers and paperboards in the World. A closer look into the raw materials of these papers is dealt in the following paragraphs. (Paulapuro, 2000)

3.1 Printing and writing papers

Printing and writing papers are used in newspapers, magazines, catalogs, commercial printing and copying just to mention a few. Printing and writing papers cover about 30 % of the paper and board markets in the world. In the Figure 8 these paper grades are listed by their quality and price. Also the primary pulp composition can be seen in the Figure 2. (Paulapuro, 2000)

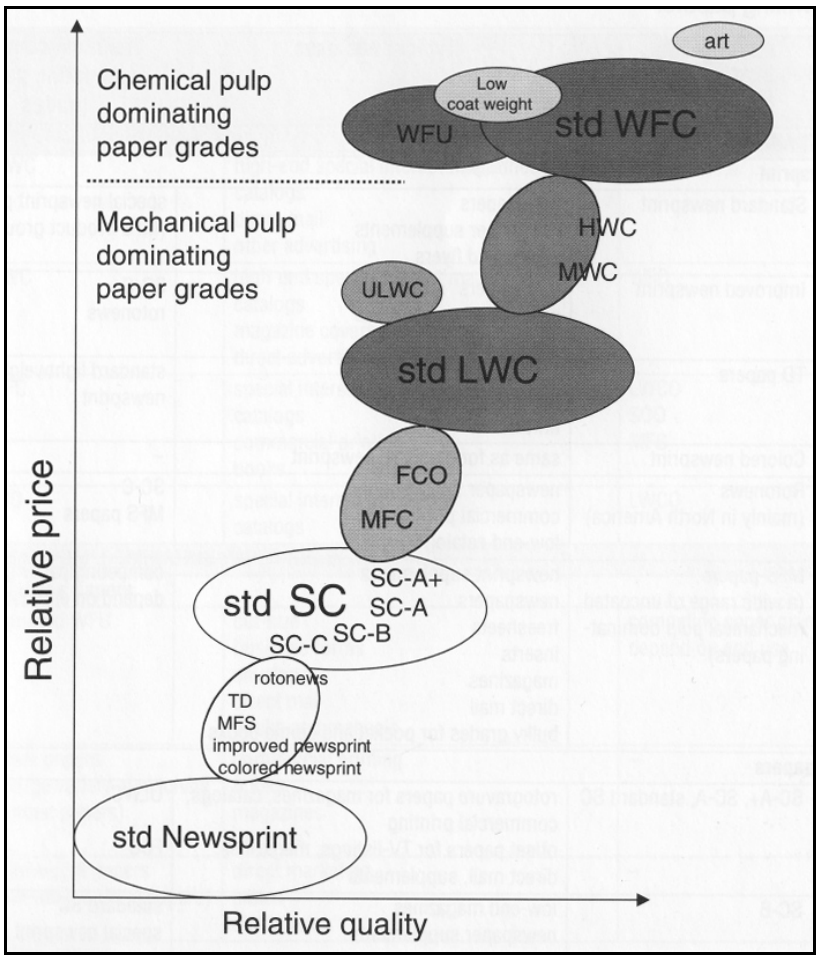

Figure 8: Printing and writing papers range (Paulapuro, 2000)

3.1.1 Newsprint

Newsprint consists of several printing paper grades of which the most important is standard newsprint. Also telephone directory and MFS papers are commonly used. Newsprint grades are delivered only in reels.

Standard newsprint

Standard newsprint is a paper grade that is mostly made out of thermo-mechanical pulp (TMP), pressure ground wood (PGW) and deinked pulp (DIP). Also some softwood might be mixed into the furnish to enhance paper strengths. In Europe the most modern paper machines produce newsprint solely out of DIP. These mills tend to have a deinking plant right beside them to improve the efficiency of production. Filler use in newsprint is tied closely to the amount of DIP used in the process. The higher amount of

grey recycled fibre used the more fillers are needed to reach the desired brightness level of the end product. The basis weights of newsprint range from 40 g/m^2 to 48.8g/m^2 and newsprint is mainly used in newspapers. (Paulapuro, 2000; VTT, 2009)

Telephone directory (TD)

TD paper is a special newsprint grade which has lower basis weight than regular newsprint. The basis weight of TD papers varies from 28 g/m^2 to 40 g/m^2. TD is produced from mechanical pulp and recycled fibre. Low levels of fillers are used due their strength deteriorating properties. (Paulapuro, 2000)

Machine-finished specialities (MFS)

Machine-finished specialities are paper grade group that includes products from a wide range of paper grades. However MFS papers are primarily produced to be used for newsprint supplements and newspapers. Mechanical pulp is the main element in the furnish of MFS papers with also deinked pulp is used. MFS papers are often brighter, bulkier and heavier than regular newsprint. (Paulapuro, 2000)

3.1.2 Supercalendered paper (SC)

SC paper stands for supercalendered paper. It has high filler content and it is mainly made out of mechanical pulp. 70%-90% of SCs furnish is from GW, PGW or TMP. The relative use of each specific pulp type is defined by which properties are required from the paper. Groundwood pulp has good optical properties and thermo-mechanical pulp has better strength properties. Also some chemical pulp (10%-30%) is needed for better strength. The fillers take up about one third of SCs furnish. Kaolin is the most used filler because of its gloss, porosity and printability enhancing properties. Small particle talc can also be used, especially in grades that are printed in rotogravure. SC paper is used for magazines and catalogues. Its basis weights range from 39 to 80 g/m^2 with 52, 56 and 60 g/m^2 being the most typical weights. (Paulapuro, 2000; VTT, 2009)

3.1.3 Coated mechanical papers

The base paper of coated mechanical papers is produced predominantly from mechanical pulp with some chemical pulp for adding strength. Papers are at least once coated. The majority of these grades are produced in reels.

Light-weight coated (LWC)

LWC papers are used for magazines, catalogues and commercial printing. Roughly 60% of the furnish is mechanical pulp and 30% is chemical. Clay, talc and calcium carbonate are used as fillers in LWC papers. They add up to 4%-10% of the whole furnish of the base paper. The total pigment content of LWC paper varies from 24% to 36% after coating. The basis weight range of LWC is from 39 to 80 g/m^2 and the amount of coat weight applied on each side ranges from 5 to 12 g/m^2. Fillers are required in LWC to enhance the optical properties of the paper and to lower cost. (Häggblom-Ahnger, 2003; Paulapuro, 2000; VTT 2009)

Medium-weight coated (MWC)

Medium-weight coated papers are not that different from LWC papers. Their furnish composition includes a little more chemical pulp than in LWC. The increased amount of coating (12-25 g/m^2 on each side) calls for more paper strength which is achieved by long fibre pulp. (Häggblom-Ahnger, 2003; Paulapuro, 2000)

High-weight coated (HWC)

The basis weights of HWC papers are as much as 100-135 g/m^2. HWC is used in high-quality magazines and in magazine covers. (Paulapuro, 2000)

Machine finished coated (MFC)

MFC papers are nearly similar to LWC papers except they usually have greater bulk which results in more stiffness. Most of MFC papers have also a matte surface. Coat weights of MFC papers are quite the same as in LWC. The fibre furnish is mostly

composed out of mechanical pulp with its percentages ranging from 60% to 85%. Generally chemical pulp is used only to bring strength but in some cases it is used as much as 40% of the whole fibre furnish. (Paulapuro, 2000)

Film coated offset (FCO)

FCO papers are also similar to LWC papers. FCO papers are used in magazines and catalogues as its main competitor LWC. The difference between FCO and LWC is the new film coating method which allows the paper to be bulkier after coating process. The nip-free coating method however leaves the surface of the paper rougher. The basis weight of FCO papers range from 45 to 65 g/m^2. (Paulapuro, 2000)

3.1.4 Woodfree uncoated (WFU)

Woodfree uncoated is a paper group that can be divided into two paper grades, offset papers and lightweight papers. WFU papers have usually only chemical pulp as fibre furnish. However some very small quantities of mechanical pulp are used in some woodfree uncoated grades. WFU papers have a filler content of 5%-30% with $CaCo_3$ being the most used filler. $CaCo_3$ is a pigment that has high brightness which is required in WFU papers. In addition to brightness, bulk, smoothness and strength properties are also important qualities. Woodfree office papers cannot lint or dust in photocopiers or in offset printing either. (Imerys Pigments for Paper; Paulapuro, 2000)

Offset papers

Offset papers are used in commercial printing, books, magazines and catalogs. Fibre furnish of office papers includes typically at least 90% of chemical pulp. The filler content can be as high as 30% but in some occasions fillers are not used at all. The basis weights of offset papers range from 40 to 300 g/m^2. The majority of offset papers are produced in sheets. (Paulapuro, 2000)

Lightweight papers

Offset papers and lightweight papers differ from each other only by their basis weight. Basis weight on lightweight papers is from 25 to 40 g/m^2. These papers are used in such

products as dictionaries and bibles. The pulp used is bleached chemical with often addition of mixes of linen, cotton and flax fibre. These papers are also called bible papers. (Etherington & Roberts; Paulapuro, 2000)

3.1.5 Woodfree coated (WFC)

WFC papers are divided into three paper grades; standard coated woodfree papers, low coat weight papers and art papers. Base paper of WFC grades is very similar to regular WFU grades. All of the WFC paper grades are single, double or triple coated.

Standard coated fine papers

The basis weight area of standard coated woodfree papers is 90-170 g/m^2. In the fibre furnish there is normally no mechanical pulp used. Total pigment content of these papers is 30%-50% with calcium carbonate and clay covering the most of these quantities. Standard coated fine papers are used in advertising materials, high-quality catalogues, annual reports and books. High bright LWC and MWC papers are used in similar products making them the main rivals of standard coated fine papers. Typically coated fine papers are produced in sheets and for offset printing. (Paulapuro, 2000)

Low coat weight papers

Low coat weight papers have basis weights ranging from 55 to 135 g/m^2 with only 3-14 g/m^2/side of coating. Like standard coated fine papers low coat weight papers are also mostly produced in sheets. The end uses vary from books to directories. Timetables and brochures are also made out of low coat weight papers. (Paulapuro, 2000)

Art papers

The basis weight range of art papers is 100 to 230 g/m^2. Art papers are coated several times and the coat weight of the end product ranges from 20 to more than 40 g/m^2 per side. Very rarely are art papers produced in reels. Art papers are used for illustrated books, calendars and brochures. (Paulapuro, 2000)

3.1.6 Special fine papers

Copy papers, digital printing papers and continuous stationery form the group special fine papers. (Paulapuro, 2000)

Copy papers

The main raw material for copy papers are virgin chemical fibres. However in some paper mills copy paper is made solely out of recycled fibre. The recycled fibre used is copy paper waste. The range of 70 to 90 g/m^2 has been the basis weight area for copy papers. The amount of pigment included can account up to 10 to 25 % in the furnish. Copy papers also have a high brightness. The ISO brightness levels can vary from 80%-96%. (Paulapuro, 2000; VTT 2009)

Digital printing papers

Digital printing papers are versatile paper category. In it there can be many different type of papers that are used in electronic printing. The basis weights can vary from 40 to as high as 400 g/m^2. These papers are mostly uncoated but the use of coated papers is increasing as the use of whole digital printing paper group is too. More and more of printing is done through electronic printing methods. And as the electronic printing methods differ from each other quite a lot, the requirements for paper differ too. This creates challenges to develop big markets for one specific product only. However the deviant requirements can also be an opportunity. (Paulapuro, 2000)

Continuous stationery

Listings and custom-made forms are the main use for continuous stationery. The papers must have high strength properties, high purity and a good dimensional stability. In these chemical fibre papers some mechanical pulp can also be used. The pigment content range is from 5% to 25%. Basis weights are from 40 to 90 g/m^2. (Paulapuro, 2000)

3.2 Specialty papers

The group Specialty papers includes the most diverse and end-use centered paper products. Every grade is designed for a special purpose with specific mechanical and optical properties. The production volumes are lower than in regular printing papers. Specialty papers category includes such grades as filter papers, thermal papers, release papers and papers used in building and packaging. Also envelope paper can be categorized in this group. Listed below there are some of the most used specialty paper grades

Label papers

Label papers are usually made of chemical pulp, mixture of hardwood and softwood. In some label papers mechanical fibre is used too. The top side of label papers is generally at least once coated. The back side is surface treated to create an even base for gluing purposes. Basis weights of label papers range from 60 to 90 g/m^2. Label papers are used in labeling products such as glass jars, tins, bottles and other packages. Labels can be self-adhesive, heat sealable or glueable. Labels are also printed in various methods such as offset, rotogravure and letterpress. Each of these printing techniques demands the paper very dissimilar surface properties. (Paulapuro, 2000; VTT 2009)

Envelope papers

Envelopes can be made out of several pulp combinations. The most common ones are bleached and unbleached chemical pulp but they can be made totally even of recycled fibre. Envelopes are made also from SC paper and kraft paper. The filler content of envelope papers varies between 0 and 15 %. Hydrophobic sizes are highly used to improve strength properties of envelopes in damp environments. (Paulapuro, 2000; VTT 2009)

Wrapping papers

Wrapping papers are used for packing all kinds of products. They should be able to protect the product from impacts and moisture with still having the appearance properties to be able to sell. Wrapping papers can be made out of every pulp, from chemical pulp to recycled fibre, depending on the needs of the product. Wrapping

papers are used e.g. in wrapping gifts, groceries, fast-food and fruit. Every wrapping paper is designed and produced for a specific end use. For example fruit wrapping paper is treated with fungicide to prevent molding. (Paulapuro, 2000)

Wallpaper

Wallpapers are made of mechanical fibre with or without a woodfree top layer. One of the most important properties of wallpaper is its printability. Wallpapers are printed in flexo, offset and screen print all of which require different surface properties. (Paulapuro, 2000)

3.3 Paperboard grades

Paperboard production is a big market area in forest industry. By CEPI estimates a third of whole paper and board production consists of case materials and cartonboards in CEPI countries in 2008. Paperboard grades are typically divided into three subcategories; cartonboards, containerboards and special boards. These categories are explained more in detail below. Defining a paperboard can be difficult as they do not differ clearly from paper. Higher basis weight has been used the most to separate paperboards from paper drawing the line to 150 g/m^2 but exceptions exist. (CEPI, 2008; Paulapuro, 2000)

3.3.1 Cartonboards

Cartonboards are products that are primarily used in consumer product packaging. Top side coating is common in all of the cartonboards. Cartonboards are divided into five different subgrades. They are folding boxboard (FBB), white lined chipboard (WLC), solid bleached (sulfate) board (SBS), solid unbleached (sulfate) board (SUS) and liquid packaging board (LPB). In the Table 2 the end uses and special requirements of each cartonboard grade are listed. (Paulapuro, 2000)

Table 2: Examples of packaged products, their special requirements for the carton and typical cartonboard grades (Paulapuro, 2000)

Product	Special requirements	Typical cartonboard grade
Direct food	Purity, cleanliness, runnability	FBB
Frozen food	Strength, barrier, purity, cleanliness, runnability	SBS, SUS
Indirect food	Runnability	WLC
Confectionery	Attractive appearance, purity, cleanliness, odor and taint free	FBB, SBS
Bottle carriers	Strength	SUS
Cosmetics, toiletries	Attractive appearance	FBB, SBS
Cigarettes, tobacco	Runnability, odor and taint free, appearance	SBS, FBB
Pharmaceuticals	Identification, runnability	FBB, WLC
Detergents	Strength, runnability	WLC, SUS
Household durables, hobby items	Strength	WLC
Textiles, clothing, footwear	Appearance	WLC, FBB
Toys, games	Strength, purity	WLC, SUS
Paper products	Appearance, runnability	WLC
Milk, juice	Runnability, cleanliness, purity, strength	LPB

Folding boxboard

Folding boxboard is used in many packaging applications such as in packaging foodstuff, cigarettes, cosmetics and pharmaceutical products. High stiffness is required for folding boxboard to ensure product protection. Boxes should remain their form when stacked upon each other. Along with stiffness purity is too an important property of FBB. No alien taste or smell can be passed from the cartonboard to the product. Such properties as high brightness and printability are required as the appearance of products have become increasingly important. Also the processability in converting machines is a desired property for FBB. (Häggblom-Ahnger 2003; Paulapuro, 2000)

FBB is formed from several layers of board. Top and back ply is made of bleached chemical pulp. The pulp used in top ply is well refined to achieve a smooth surface for better printing result. Also the bright bleached pulp used in top ply improves the appearance of the product. The basis weight of top ply varies from 45 to 60 g/m^2 and for the back ply from 25 to 30 g/m^2. Basis weight for folding boxboard varies from 160 to 450 g/m^2. The basis weights of outer layers remain quite similar in every grade, the basis weight changes of the end product is controlled by altering the basis weight of the middle ply. Middle ply is made out of mechanical pulp to give high bulk which results in better stiffness. Folding boxboard is coated usually on the top side but also back side

coated and totally uncoated FBB is produced. (Häggblom-Ahnger 2003; Paulapuro, 2000)

White lined chipboard (WLC)

WLC is a multi-layer cartonboard grade with its top and back ply made of bleached chemical pulp and middle ply made of old corrugated containers, mixed waste and mechanical pulp. In some grades in the back ply some DIP and OCC can be used as well. In between the top and middle ply there is usually an undertop ply. It is made of DIP, white ledger and mechanical pulp. Its purpose is to lessen the use of expensive chemical pulp in the top ply without losing good brightness values due to the middle ply. The middle ply is very low in brightness. WLC has generally coating on the top ply to ensure good appearance of the package. Basis weights of WLC range from 200 to 450 g/m^2. (Häggblom-Ahnger 2003; Paulapuro, 2000)

White lined chipboard is used in the same purposes as FBB but because of the recycled fibre used in the middle ply it cannot be used in every food packaging applications. However, together with plastic bag WLC is used in packaging groceries. (Häggblom-Ahnger 2003; Paulapuro, 2000)

Solid bleached board (SBS)

Solid bleached board is produced entirely out of bleached chemical pulp. The main pulp used is bleached hardwood sulfate. It is used because it gives good formation and good printing properties. Bleached softwood is used as well in the furnish. In new applications some Chemi-Thermo Mechanical Pulp (CTMP) have been started to be used in the middle ply of SBS. Solid bleached board is a board grade that can be produced as single-ply and multi-ply product. The conventional SBS grade is a single-ply with coating on top. The multi-ply SBS usually consists of three plies with coating layer on top. With the multi-ply SBS more end-use focused board can be easily produced. The outer plies can be optimized to have good brightness and printing properties whereas the middle ply can be produced to bring the board suitable bulk. Especially if CTMP is used in the middle ply high brightness values are required from the top ply. (Häggblom-Ahnger 2003; Paulapuro, 2000)

SBS is used in similar products as FBB and WLC. For chocolate and cigarette packaging SBS is often chosen due to its good odor and taint properties. (Häggblom-Ahnger 2003; Paulapuro, 2000)

Solid unbleached board (SUS)

Solid unbleached board is usually made of two or three plies where every one of the layers is of unbleached pulp. Top ply is mainly short fibre hardwood pulp to ensure even base with good formation for coating. The back ply of SUS is made of unbleached softwood kraft. Stiffness is a very important feature in SUS and all of the cartonboards. Correct amount of refining of the pulps in the top and back plies with bulky middle ply results in good stiffness. In the middle ply there is unbleached softwood kraft and broke as fibre component. Also recycled fibre and OCC are used in some mills. SUS is used for consumer packages of beverages. (Häggblom-Ahnger 2003; Paulapuro, 2000)

Liquid packaging board (LPB)

Liquid packaging board is used for packaging different type of liquids with milk and juice being the biggest market. Barrier properties are the most important features in LPB. The packages should protect the product from gases, aromas, moisture and other liquids. The protection of a LBP package is made in converting where usually plastic film or laminated aluminum foil is applied on top of the cartonboard. (Paulapuro, 2000)

Purity and cleanliness are absolute when packaging foodstuff, therefore only virgin fibre can be used. The main furnish components of multi-ply LPB are bleached or unbleached chemical pulp. LPB can be coated and it can even have CTMP in the middle ply for higher bulk. Even though LPB products are printed they do not necessarily require excellent surface properties. Most of printing is made using flexo method which does not demand e.g. high smoothness. (Paulapuro, 2000)

3.3.2 Containerboards

Containerboards include the grades linerboard and corrugating medium. These grades are used to produce corrugated packages. These packages are broadly used around the world making containerboards a big business. Use of corrugated board is on the

increase and it has even started to replace FBB and SBS in some consumer packaging markets.

Linerboard

The top and back board in corrugated boards is called liner. Two different liners are used to produce modern corrugated packages. These two are kraftliner and testliner. In kraftliner the composition of the pulp is made mainly of virgin fibres whereas in testliner most of the fibres are recycled. Basis weights of linerboards range from 125-350 g/m^2. Linerboards are also constructed in plies like other boards. (Paulapuro, 2000; VTT 2009)

In kraftliner the base and top ply are made of unbleached brown softwood fibre but the fibres used in the top ply are processed differently to obtain better optical properties. As mentioned before good appearance properties are required from linerboards that are used in consumer packaging. Using bleached hardwood and softwood in the top ply is also commonly used. This liner is called white top linerboard. The white short fibre pulp makes a brilliant surface for visual appearance and printing. Fillers are also commonly used in the top ply of white top linerboards. They bring better opacity levels for the product. (Paulapuro, 2000; VTT 2009)

Testliner is made mainly of OCC, DIP and other recycled fibre. Virgin fibre can be used in the top ply for appearance properties. Testliner is usually made of four plies because of better production controllability. Dewatering in the forming section of the board machine is easier to control when several headboxes are used. (Paulapuro, 2000; VTT 2009)

Corrugating medium

In corrugated boards the wavy middle layer is called corrugated medium. It can be made of semichemical pulp or recycled fibre. Basis weights of corrugated medium vary from 110 to 180 g/m^2. In this single-ply product the most important properties are strength properties and especially compression strength. (Paulapuro, 2000; VTT 2009)

3.3.3 Special boards

In special boards there are a number of boards that are produced small amounts throughout the world. Most of these are products that are utilized in industry use. Core board, plaster board and wallpaper base are of products that occupy this category. (Paulapuro, 2000)

There are lots of different paper and paperboard grades in the world. Each of them has their own properties and furnish compositions. To define a grade accurately is difficult as production methods and pulp composition differ from each other around the world. In table 3 some general lines of paper grade raw materials are depicted. Use of raw materials is changing towards less expensive combinations. Recycled fibre use is increasing all over the world. The percentages in the table are rough estimates.

Table 3: Fillers and fibre estimates of paper and paperboard grades

Grade \ raw material	Fillers	Mechanical	Chemical		
		TMP, PGW	Hardwood	Softwood	DIP
News	5-15 %	40 %	0 %	x	45 %
TD	0-5 %	45 %	0 %	x	50 %
MFS	0-5 %	70 %	0 %	0 %	30 %
SC	20-30 %	55 %	x	15%	x
LWC	5-10 %	60 %	10 %	20 %	x
MWC	5-10 %	60 %	10 %	25 %	x
HWC	5-10 %	60 %	10 %	35 %	x
MFC	5-25 %	90 %	x	10 %	0 %
FCO	5-10 %	60 %	10 %	20 %	x
WFU	5-25 %	0 %	45 %	30 %	0 %
WFC	5-25 %	0 %	40 %	40 %	0 %
Label	10 %	0 %	40 %	40 %	0 %
Envelope	0-15 %	x	45 %	40 %	x
Wrapping	5-20 %	x	x	x	x
Wallpaper	5-15 %	65 %	20 %	0 %	0 %
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 %	x
LPB	0-5 %	0 %	80 %	20 %	0 %
Linerboard	5-10 %	0 %	20 %	70 %	x
Corrugated med.	0 %	x	0 %	0 %	100 %

(x = can be used)

4 Paper markets

Paper consumption in the World has risen steadily during the last decades and continues to do so in the future. The location of future markets however has recently changed. The demand for paper has dropped rapidly in Europe and North America during the last five years. Asian markets in contrast have grown in every paper grade. (McIlroy, 2008)

4.1 Current production

According to Food and Agriculture Organization (FAO) estimates nearly 380 million tons of paper and paperboard was produced in the year 2008. The production amount has been growing steadily year by year from the sixties to 2007. The production amount of 2008 is slightly smaller than in 2007. Recent shutdowns of several paper mills and poor economic situation have caused this minor decrease. Over 90 % of paper and paperboard is produced in Asia, Europe and North America. Asia is the biggest producer with 34 % of all production and Europe and North America are trailing with 30 % and 29 % respectively. (FAO; McIlroy, 2008)

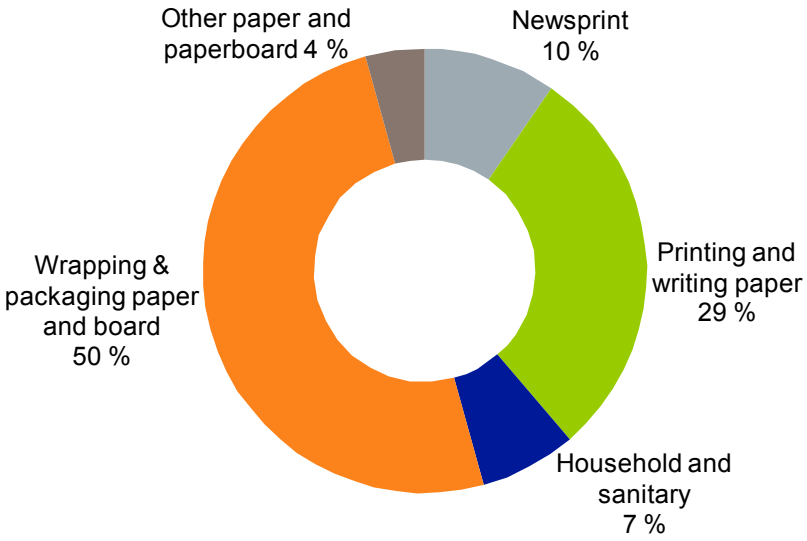

Figure 9: Global paper and paperboard production by grade in 2008. (Finnish Forest Industries 2009)

50 % of whole paper and paperboard production consists of packaging material production of which corrugated board production takes more than half. Figure 9 shows also clearly the considerable magnitude of printing and writing paper production. The production shares have remained similar with only minor changes during the last years.

4.2 Paper and paperboard demand

Paper demand and consumption is on the rise. The average global growth in paper and paperboard demand is estimated to be about 1.9 % / year. The growth of production is projected to be negative in Western Europe, North America and Japan, which can be seen in the Figure 10. The current production capacity of these regions is large, about 60 % of the total production. (IPTS, 2006)

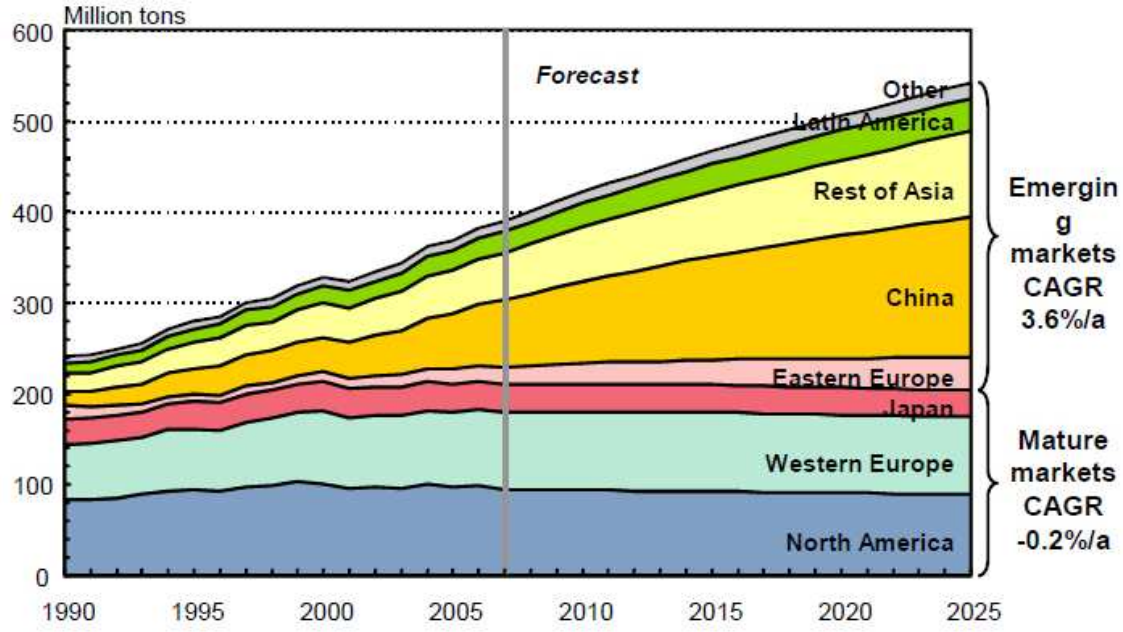

Figure 10: World demand for Paper and Paperboard 1990-2025 (Kokkonen 2009)[2]

New markets have emerged in Asia and Eastern Europe. Such countries as China and India have shown increasing demand for paper for books and newspapers. The demand growth rate in China is estimated to be close to 5 % / year. (IPTS, 2006; Pöyry, 2006)

[2] Original source: Pöyry Forest Industry Consulting, 2007

The main reasons for growing demand in emerging markets are population growth and increasing living standards. Higher GDP per capita has lifted paper consumption to new heights. This can be seen in the Figure 11. It depicts the long-term demand growth by each product area. The growth in demand of tissue paper is far above the average demand growth. Consumption of tissue paper has a high relation to increasing living standards. (IPTS, 2006; Pöyry, 2006)

Naturally the foreign investments to the developing countries have had an impact also. Construction of several industrial production plants has increased the demand of packaging boards. Especially containerboards are increasingly required as products are shipped from Asia to other countries. The demand growth can be seen in the Figure 11. Cartonboards have high demand growth as well.

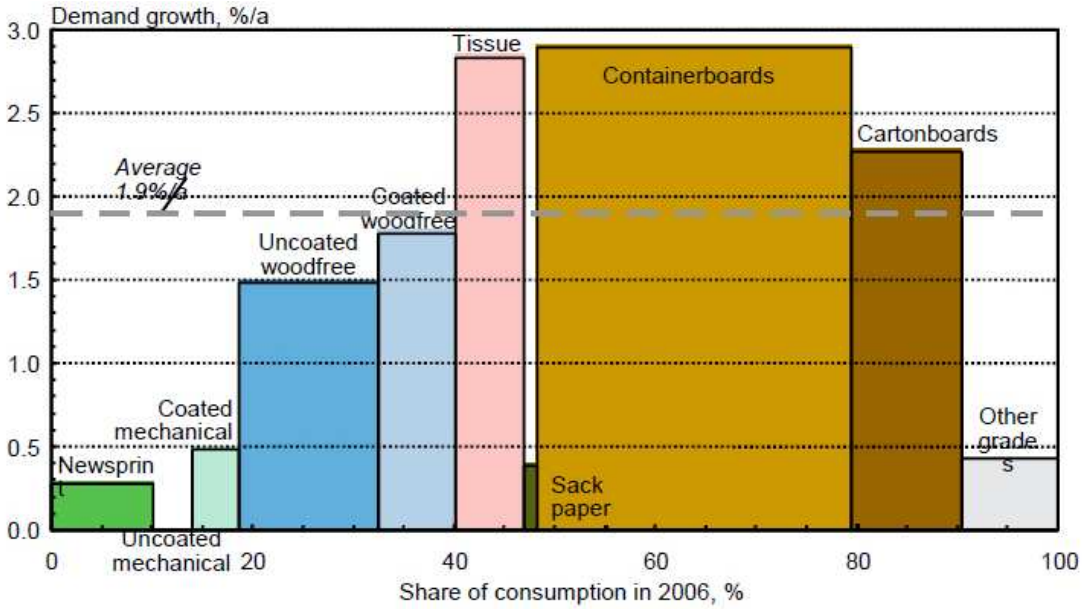

Figure 11: Long-term demand growth by product area through 2025 (Kokkonen 2009)[3]

[3] Original source: Pöyry Forest Industry Consulting, 2007

5. Potential grades for new markets

The target of this work was to find out which paper or paperboard grade would be suitable for filler-for-fibre change. The most interesting grades were the ones that gained in mechanical or optical properties and still lessened the production price of the product. Cost-effectiveness of the product was comprised especially of replacing the expensive chemical pulp fibre with fillers.

An exclusive list of grades was selected from all of the paper and paperboard grades listed above. The list consists of grades that have high amounts of chemical pulp in the furnish. These grades are woodfree uncoated, woodfree coated, envelope paper, label paper, folding boxboard, solid bleached sulfate, solid unbleached sulfate, white lined chipboard and liquid packaging board. Future possibilities of developing these grades are contemplated in the following chapters.

5.1 Woodfree grades

Woodfree uncoated is a grade that is composed of chemical pulp fibre. Fibre furnish consists of bleached hardwood pulp, usually birch, 55-80 % and bleached softwood 0-30 %. Filler materials take up 10-25 % of the whole furnish. In WFU grades PCC is often used as the main filler. The brightness values of WFU range from 86 to 92 % and opacity values from 83 to 98 %. (Paulapuro 2000)

The highest brightness and opacity values of WFU grade are very high. These values are only higher in coated grades. Therefore to increase brightness and opacity of WFU is becoming difficult. Any effort to do so and have show in results is rewarding; all customers are interested in brighter and less opaque paper almost no matter the cost.

Chemical pulp fibre is expensive making the WFU grades costly. Even with high filler contents, which is 25% of the whole furnish, the paper grade is pricy due to high rates of NBSK, northern bleached softwood kraft pulp. The price of NBSK was about 740 euros / ton in the beginning of May. (FOEX, 2010) A cheap filler costs 85 % less. To be able to reduce the amount of chemical pulp fibre with considerably cheaper filler, better production economics could be obtained. Greater profits would be in reach. Replacing fibre with filler bring many obstacles papermaker needs to overcome.

Strength properties are important to every paper grade and WFU is no exception. In general, fillers weaken paper strength. In forming they block fibre-fibre bonds. Even though most of the WFU papers is produced in sheets tensile strength is needed especially in grades that have low basis weight. Surface strength is also essential for WFU as many WFU products are printed in offset. Offset is a printing method that demands high surface strength in paper and bears no linting or dusting of the paper. Surface sizing is used to improve strengths on top of the paper. Also dimensional stability is important in woodfree grades that are used in offices. To be able have good runnability in copier machines by adding more fillers would surely interest customers.

In woodfree grades that have low basis weight adding filler content might be difficult. All strengths would suffer dramatically as the fibre network is not strong. Printing and converting might prove to be challenging.

Woodfree coated is quite a similar grade compared to WFU. The base paper of WFC grades differ from WFU mainly by surface properties. In the base paper of WFC generally porosity and absorption levels are different. Using fillers to optimize the affinity of coating layer on the base paper could prove to be beneficiary in costs. Fewer binders would be necessary.

Adding bright fillers could also lessen the use of coating itself. By reaching higher brightness in base paper the use of coating colour or coating phases could be decreased. Brighter base paper would at least help in reaching desired brightness levels after coating.

5.2 Special papers

Envelope papers are required to have good opacity. By adding fillers better opacity can be reached. The size of filler particles, refraction index and the amount of pigment-air interfaces affect paper opacity.

Label papers should have good strength properties due to high processing in converting machines. Appearance properties of label papers are of greatest importance. They are used to give information about products and to wake the customer to buy the product. All labels are printed, which required high smoothness levels too.

5.3 Paperboards

The use of fillers in paperboards has been limited by its adverse impact on strength and bulk. As a result there has been little filler use replacing chemical fibre in the middle plies of paperboards. The use of fillers has been concentrated on the top plies to give better optical properties for the paperboard.

Adding of fillers increases the ash content and helps dewatering. The drying of thick webs of paperboard can be quite expensive. To gain energy savings in drying and could be possible to lessen the expenses of the furnish

6 Conclusion

In this work, paper and paperboard grades that have a big share of chemical fibre in their furnish were selected for a closer inspection. The driving idea of selecting these grades was to lessen the use of chemical fibre by replacing it with fillers and thus lowering the costs of the product.

Paper industry in recent years has gone under many changes. Several paper mills have been shut down and all costs have been cut back. This has forced the industry to come up with new, more economic ways of producing paper and paperboard. One of these methods is to replace fibre with cheaper materials without losing in important properties.

Increase in filler amounts has many beneficiary effects. Savings through less fibres, improved optical properties and better printability are some of the assets filler use brings. With great assets come also challenges. The deteriorating of properties e.g. strength properties is important to take into account.

In near future filler use will increase. Such grades as PCC are becoming more and more popular around the world. At the same time kaolin and ground calcium carbonate are still consumed at high levels. Biggest markets in coming years will be concentrated in Asia, especially in China. As standards of living grow, more paper is going to be consumed. Printing and writing grades are the first to grow.

The high growth projection of packaging materials does not surprise either. Many producers from every possible field have centered their production in Asia. Fibrous packaging is used in shipping their products around the world.

New brighter, less opaque and cheaper paper and paperboards will be seen in the following years. New paper and paperboard mills built in Asia will give business opportunities for chemical companies to get a foothold in close quarters with paper industry.

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