Chip Geometry

Methods to impact the geometry of market chips

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Abstract

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In general there is an understanding that geometrical consistency of chips is desirable in the pulping processes (both for mechanical and chemical pulping). Scandinavian pulp mills normally communicate requirements for chip geometry to the producers through quality regulations and bonus penalty systems. To optimize their deliveries sawmills try to produce chips of optimal size and screen out undesired fractions, and as a standard procedure they re-chip oversized chips into acceptable sizes. This thesis evaluates the level of consistency of market chips and the possibilities to increase consistency. Studies were conducted in the value chain from the point of chip production in sawmills to the point of delivery at the pulp mill gate. The geometry of chips from a single sawmill is almost as uniform as that of chips made by a pulp mill and the geometry is relatively consistent over time. However the geometry differs among sawmills and the resulting mix can be expected to have low consistency. There are possibilities to increase total consistency by steering chips from different sawmills toward common geometrical targets. In 2001 an additional (fifth) screen was introduced in the SCAN-standard for measuring chip fractions, with the aim to increase possibilities to promote consistency. When constructing bonus penalty systems for the new standard it is important to take into consideration the effects the additional screen has on the classification result. Oversized chips that are re-chipped were found to differ from ordinary market chips in geometry, in addition to having high content of bark and defects.

Keywords: Chip geometry, chip dimensions, chip market, chip quality, re-chipping, wood chips

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Appendices

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Bjurulf A. (2005a): Dimensional consistency of wood chips over time, Nordic Pulp and Paper Research Journal vol 20 no. 1/2005, 43-47.

II. Bjurulf A. (2005b): Effects on chip size distribution when an extra screen is added in SCAN:CM 40:01, Tappi Journal, March 2005, vol 4:no 3, 28-31.

III. Bjurulf A., Ekström J., Fuglem G., Sørli A. & Tooley C. (2006): Possibilities to control chip dimensions, examples from two sawmills, submitted.

IV. Bjurulf A. & Rosenquist B. (2006): Re-chipping of oversized chips in sawmills, manuscript.

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Introduction

This thesis is formulated from the view of pulp and papermaking, emphasis is on the interface between the pulp industry and the producer of market chips (Fig. 1). From Edberg, Engström & Hartler (1971) I have adopted the term "market chips" for purchased (mainly sawmill) chips. The thesis is based on Scandinavian conditions and chips from Norway spruce (*Picea abies*).

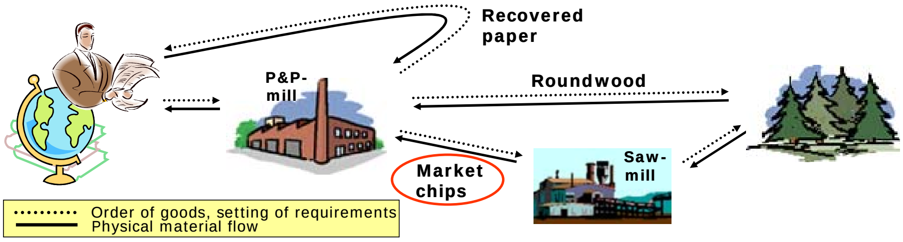

Fig. 1. Fiber raw materials of the pulp and paper (P&P) industry. The market chip flow is highlighted with a red circle.

The tree

A general understanding of trees helps in understanding the text, even though this thesis is not about wood and fiber properties. In the context of papermaking, fibers stand for tracheid cells in softwoods and libriform cells in hardwoods (Table 1).

Table 1. *Cell types in spruce, pine and birch (Ejderby, 1975)*

	Norway spruce (*Picea abies*)	Scots pine (*Pinus silvestris*)	Birch (*Betula pendula*)
Vessels	-	-	25%
Fibers, tracheids	95%	93%	-
Fibers, libriform cells	-	-	65%
Parenchym cells	5%	7%	10%

Table 2. *Wood compounds for spruce, pine and birch (Sjöström, 1981)*

	Norway spruce	Scots pine	Birch
Cellulose	41.7%	40.0%	41.0%
Hemicellulose	24.9%	24.9%	29.8%
Lignin	27.4%	27.7%	22.0%
Other polysaccharides	3.4%	3.6%	2.6%
Total extractives	1.7%	3.5%	3.2%
Residual constituents	0.9%	0.3%	1.4%

The structure of the cell wall is important for the properties of the wood. The cell wall consists mainly of cellulose, hemicelluloses and lignin (Table 2). Cellulose is long glucose chains and the main structural component in the cell wall. In wood it exists in the form of microfibrils which are generally thought to be more or less square in cross section (Fig. 2). Hemicelluloses are relatively short and branched glucose chains, also an important compound of the cell wall. The third major component of wood is lignin. Lignin is completely amorphous (Eaton & Hale, 1993).

Wood consists mainly of the elements carbon (50%), oxygen (44%) and hydrogen (6%), in addition there is about 0.5% minerals. These figures are essential for explaining the energy content of wood. Hydrogen has almost four times higher energy content than carbon while oxygen does not contribute to the energy content of wood at all. For comparison it can be mentioned that oil contains about 86% carbon, 12% hydrogen and 2% sulphur and hence contains more energy than wood. Energy content per dry weight unit is quite stable among different wood species. The energy content of wood varies with moisture content, the efficient energy content can be estimated by the formula $5.32 - 0.67 \times u$ MWh/BDT (u = moisture weight / dry wood weight, BDT = bone dry ton) (Nylinder, 1979; Nurmi, 1993; Gjølsjø, 1999).

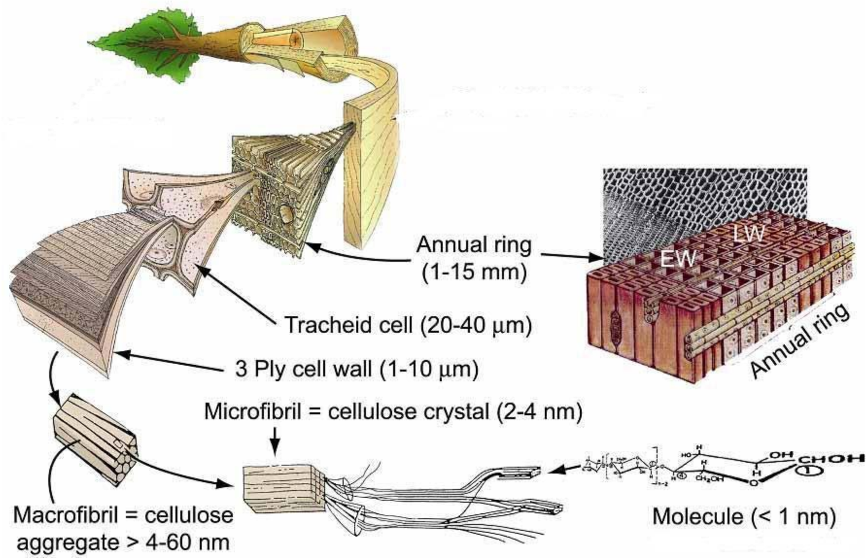

Fig. 2. Softwood structure (with permission of G.Daniel, Swedish University of Agricultural Sciences, WURC (modification from Harrington)).

The wood and fiber properties vary between trees, and within a tree. The example shown in Fig. 3 illustrates well some principal fiber property distributions within a tree. Since sawmill chips come mainly from the slab wood from the outer part of the trees, they have some special characteristics compared to chips produced from pulpwood – sawmill chips generally have high initial moisture content, rather high basic density, and contain long, rather coarse fibers (not very flexible).

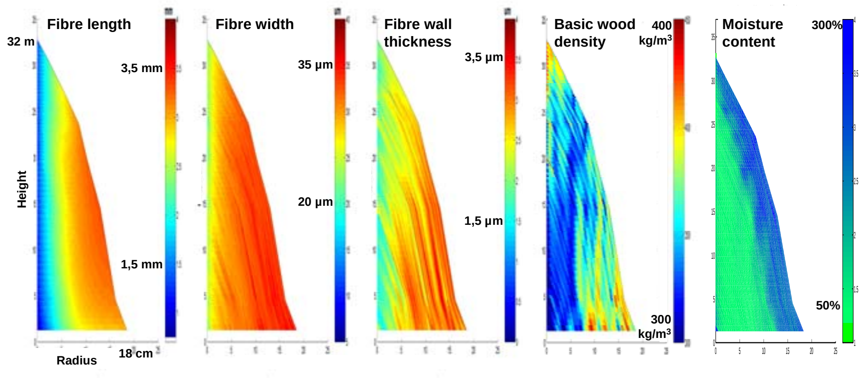

Fig. 3. Wood and fiber properties within a spruce tree (the first three from left with permission from Lundqvist, STFI, yet unpublished, the two at the right Lundqvist, 2004).

The wood market – a value system

The logistic flows of the wood market in Scandinavia is both strongly diverging and converging at the same time (Bjurulf et al, 1993a). At a harvesting site it is not unusual with 5-10 different assortments going to different customers, for example spruce sawlogs, pine sawlogs, special grades sawogs, small dimension sawlogs, spruce pulpwood, pine pulpwood, broad leaf pulpwood, energy roundwood and harvesting waste for energy production (see also Table 3). On the other side, a pulp mill receives pulpwood from maybe 30 000 harvesting sites yearly and maybe 10 sawmills. The same is true for sawmills, normally having a large amount of suppliers and a large number of customers.

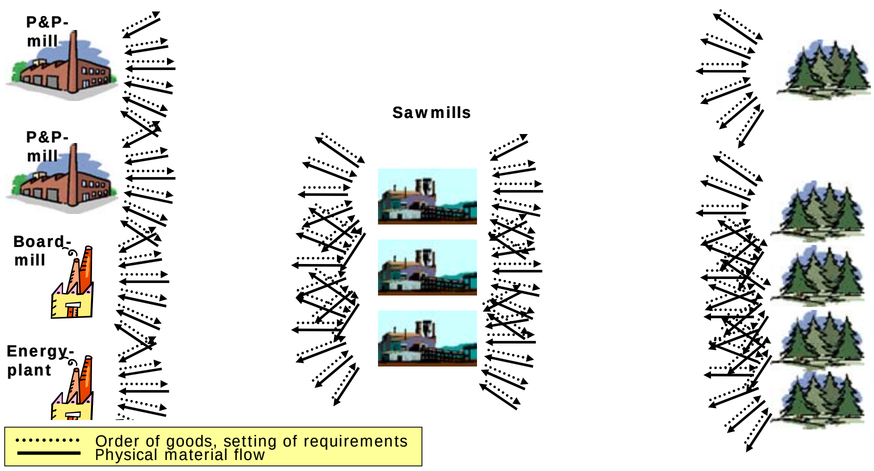

Fig. 4. Fiber value system.

Fig. 4 is simplified – other actors exist and cross-selling is common. The purchasing organizations of both sawmill and pulping industries often purchase all products from a harvesting site and then sell the non-core business products, thereby playing the role of traders/swappers. It is not unusual with traders or forest owner associations, doing raw material purchasing and wood flow organization for the industry. Most of the harvesting and transport is outsourced to specialized companies. All these activities form a complex network. A chain of value-adding activities is called a value chain and industry wide synchronised interactions of local value chains create an extended value chain, called a “value system” (Porter, 1985).

An obvious consequence of the large amount of suppliers and possible customers, all the way from the forest to the ready-to-deliver paper, is that the products within the value chain tend to be regarded as commodities. Therefore physical quality and other requirements are handled in relatively formalistic systems.

Another characteristic of the wood market is that the different products, especially roundwood, have wide property gradients. Depending on wood properties the roundwood is sorted into different product groups called assortments. These assortments are to a large extent exchangeable. An example is given in Table 3, where the quality requirements and price of logs from a given tree species, are highest on the top of the list. Generally higher grades of wood can be utilized for lower applications and uses. There are exceptions, for instance a small-dimension-sawmill can not utilize more expansive larger sawlogs.

Table 3. *Example of spruce log assortments. Price relations for the grades above “high quality pulp wood” are calculated from average prices, Norway 1999-2003 (SSB), in this price series average price for high quality spruce pulp wood is 239 NOK/m³sub. Price relations for the lower grades have been taken from the price list of forest owner association Viken in Norway, July 2005 (zone 2), the price for high quality spruce pulp wood was 251 NOK/m³sub in this price list. In Sweden it is common with a low quality pulp log assortment used for chemical pulping, with higher permitted rot content. This assortment has a price of about 90%, of the high quality spruce pulp wood price (price list of Stora Enso Örebro, July 2005). In many places there are also assortments for small dimension sawlogs, paid about 30% higher than pulp wood*

Wood assortments	Example of applications/uses	Price, % of high quality pulp wood
Special timber	Special products	220%
First class sawlogs	Furniture	180%
Second class sawlogs	Construction	141%
Other sawlogs	Low quality sawnwood	133%
Pulp logs – high quality	Newsprint	100%
Pulp logs – low quality	Chemicals (sulphate process)	57%
Energy wood logs	Energy	53%

A special mark for the raw material of the pulp industry, is that it is not the core business product of the suppliers. The prime quality focus of forest owners is most often to produce high quality sawlogs (highly priced) and that of sawmills is to produce sawnwood. Nevertheless the pulp industry has strict requirements on the raw material they utilize.

Yields, from forest to paper

In Scandinavia about half of the wood quantity from a harvesting site becomes sawlogs, and the remaining part in general becomes pulpwood and bioenergy wood. In some countries the board industry also consumes large quantities, but this industry is rather small in Scandinavia.

Table 4. *Yield of the total harvesting in Norway 2003, all species (SSB)*

Sawlogs	48%
Pulpwood	40%
Energy wood logs	12%

In sawmills about half of a sawlog become sawnwood, one third becomes chips, mainly delivered to the pulp industry, and the remaining part is usually used for energy or in the board industry.

Table 5. *Yield from sawmills in Sweden 2000 (Staland, 2002). In addition, the bark amounts to about another 11% (volume) (Tamminen, 1977)*

Sawnwood	47%
Chips	34%
Saw dust	10%
Slabs	1%
Rest	8%

For pulpwood it is normally a precondition that the bark should remain on the logs as far as possible. The main reason is that the bark protects the wood, primarily from drying. The bark amounts to about 13% of the volume of pulp logs (Tamminen, 1977), though the harvesting and logistic activities remove some of the bark, especially in periods of sap flow. The logs are normally debarked before pulping. In this process also about 2% of the solid wood is removed from the logs. This wood is not entirely lost, but follows the bark and is used for energy production.

Before making paper the wood fibers have to be separated. The separated fibers are called pulp. In some pulp mills the logs are ground on large grindstones, thereby separating the fibers from the logs. Other methods are chip-based, starting with chipping the logs (or with purchased market chips) and thereafter refining the chips mechanically (for example TMP – thermo mechanical pulping), or boiling the chips with special chemicals for separation. So, the fiber separation can be done mechanically or chemically, or by combined methods. In most mechanical refining systems the chips are to some extent treated with heat and/or chemicals before refining.

With different pulping and papermaking processes the end-product acquires specific and very different properties. Examples of distinctly different products are grease proof and tissue paper. The yield of a pulp mill varies with the process used.

In mechanical processes almost all of the debarked wood becomes pulp – about 97% yield (Fig. 5). Spruce has a basic density of about 0.37 BDT (bone dry ton) per m³ and the wood consumption may be 97% × (100% - 10%) / 0.37 ≈ 2.4 m³ per ADT pulp (air dry ton = 10% moisture content). Paper made from mechanical pulp is mostly used for publication purposes; newspapers and magazines.

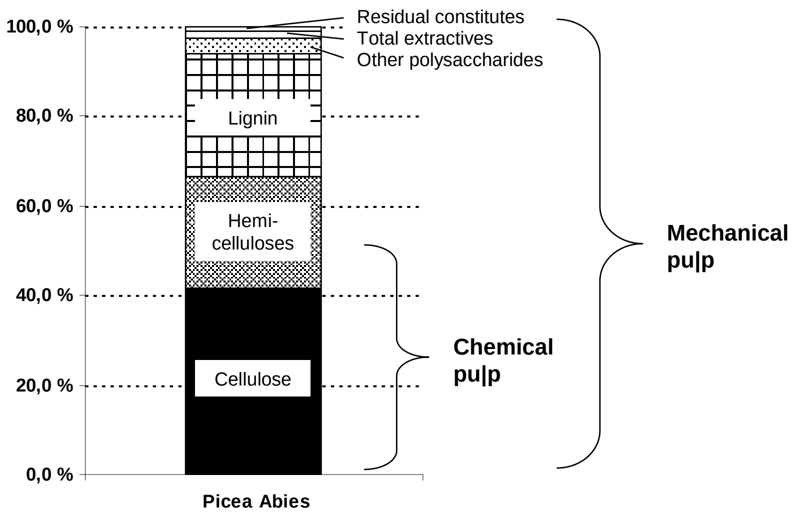

Fig. 5. A principal sketch of yield for chemical and mechanical pulping. Compounds of spruce (Picea Abies) from Sjöström (1981).

Paper made of mechanical pulp turns yellow when exposed to daylight (old newspapers for example). It is the lignin that is sensitive to light. In the chemical processes most of the lignin is extracted from the wood and thereby the fibers are separated. Also more or less of the hemicelluloses are extracted, and the result is cellulose. The harder the process is run the more pure the cellulose pulp. In a normal sulphate process about half of the wood is extracted (Fig. 5) and the yield is about half of that of the mechanical process, the wood consumption may then be 5 m³ per ADT pulp. The extracted part of the wood is used for other products, for example energy. A chemical pulp mill normally produces more energy than it consumes, while a mechanical pulp mill uses much energy for fiber separation. Paper made of chemical pulp is quite light resistant and can be employed for archive use. Chemical pulp is also used for products with strength requirements and sanitary products.

Recovered paper is an important raw material for paper making. In Europe the recycling rate is 52% and worldwide 49% (European Recycled Paper Council, 2004).

Log properties

Pulpwood properties, commonly used for setting requirements in Scandinavia, are:

- Allowed species. Species differ in wood and fiber properties.
- Freshness: The requirements are often set as time elapsed between felling and delivery, the requirements can also be expressed as moisture content. The drying of wood after felling varies with temperature, wind, air dryness, shadowing etc (Persson, Filipsson & Elowson, 2001; Berg et al, 1995), see also Fig. 6. The focus on lead time has increased dramatically. In the early 80's the time from felling to processing the pulp log was approx two months (Bjurulf, 1994), in 2003 a study in Norske Skog (Bjurulf, yet unpublished) gave the average result 3 days from felling to road side, 4 days from road side to mill gate and 14 days on the wood yard before processing. Whereas some pulp mills want as fresh wood as possible others requires a somewhat matured raw material. Once the stem is cut off from the butt, the resin maturing begins. When wood dries out (a critical moisture content of 40% has been mentioned) processability is affected (Bjurulf, 1993b), the effects are illustrated in Fig. 7 and 8.
- Biological degradation: Storage decay is normally not allowed. For forest rot the requirements are set as maximum allowed content. Biological degradation decreases yield. For mechanical pulping it also decreases the brightness of the unbleached pulp. Another effect is that chips made from rot infected logs have more variations which lead to a more unstable mechanical process. This has negative effects on energy consumption and pulp strength.
- Log geometry: Accepted diameter and length intervals are normally stated. The general aspect of the log diameter is related to the debarking and chipping processes. Big logs tend to break small logs and causes wood losses. The input opening into the chipper also sets a restriction. The more uniform length of pulpwood, the more efficient the handling, all the way from the harvesting site to the chipper at a pulp mill. Odd shapes, like crooked logs (i.e. bow-shaped logs) or forked logs are normally not accepted (the definitions on fork and crooked varies). Odd shapes cause problems in the handling and increase the risk of an insufficient debarking result.
- Contaminations: Metal, stones, plastics, radioactivity, chemicals etc are not allowed.

In addition to setting absolute requirements for properties, pulp mills could benefit from having more detailed information on fiber and wood properties. For example information regarding density, compression wood, juvenile wood, late-wood contents, cell lengths, cell widths, cell wall thicknesses and micro fibril angels. From information on stem diameter number of annual rings, growing site and altitude and some other easily accessible parameters, it is possible to predict several fiber properties (Lundqvist, 2004). The information can basically be utilized in two ways:

- mix the raw material for maximum quality stability or
- sort the raw material in quality classes appropriate for different products.

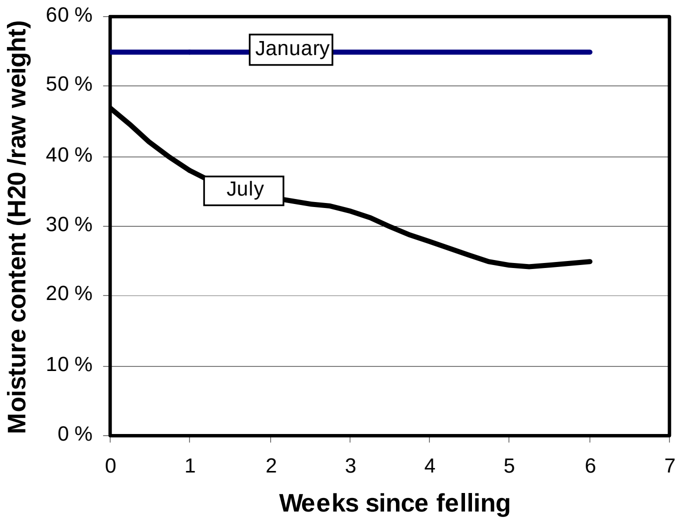

Fig. 6. Dry-out studies of wood cut in January and July, and stored in bundles at a wood yard. The bundles were weighed in the cutting week and for the following six weeks. Bundles were also cut and studied in March, April, May, June and August, The June bundle was close to the July in dry out progress, the May bundle somewhere in between January and July and the other closer to the January bundle (Berg et al, 1995), the work of Persson, Filipsson & Elowson, (2001) supports this picture.

The effects different wood and fiber properties have on the logistic chain, chipping processes, pulping processes, paper processes and the properties of the ready to deliver paper are often rather complicated to predict. The reasons are that there are many different processes involved in the value chain and that the different properties co-vary and interact. Fig. 7 and 8 show examples of this.

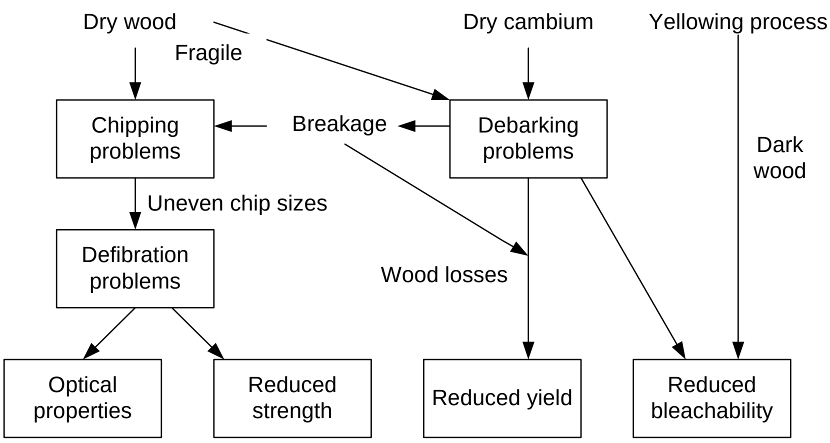

Fig. 7. The relationship between freshness and processability, mechanical pulping (Bjurulf, 1993b).

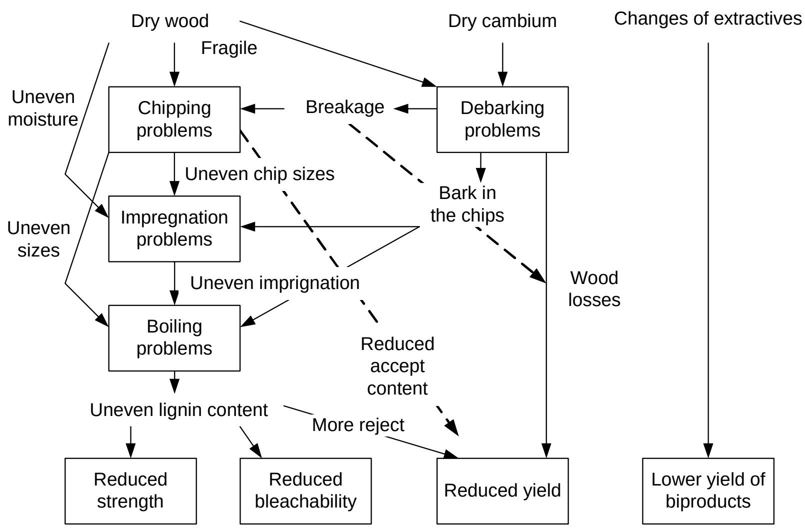

Fig. 8. The relationship between freshness and processability, chemical pulping (Bjurulf, 1993b).

The requirements on sawmill logs are strict for straightness and no biological degradations should have taken place. The sawlogs are often classed and priced according to systems involving many parameters related to shape, knots, annual rings etc.

Chip production

It is principally the outer part of the logs that become chips (Fig. 9).

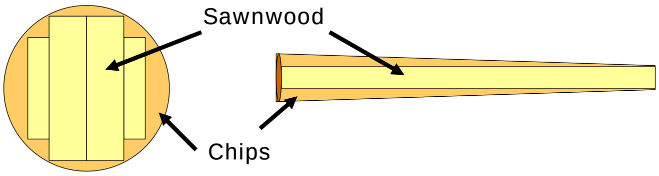

Fig. 9. In sawmills logs are turned mainly into sawnwood and chips.

Chips are generally produced in several stages within the sawing process, in several different machine centres and with equipment, primarily constructed for obtaining high-quality sawnwood. The major part of the chips is generally produced in two main log breakdown centres. Many sawmills have sideboard trimmers that also produce chips, if slabs are produced they are most often run through a drum chipper. At most sawmills pieces from the end-trimming of the un-dried boards are chipped.

To achieve the quality required by the customers, chips are run through an online screen in order to screen out as much as possible of the non-desired fractions. In many sawmills oversized chips are thereafter processed in a drum chipper, reducing them to smaller fractions and then brought back for screening again (Fig. 10).

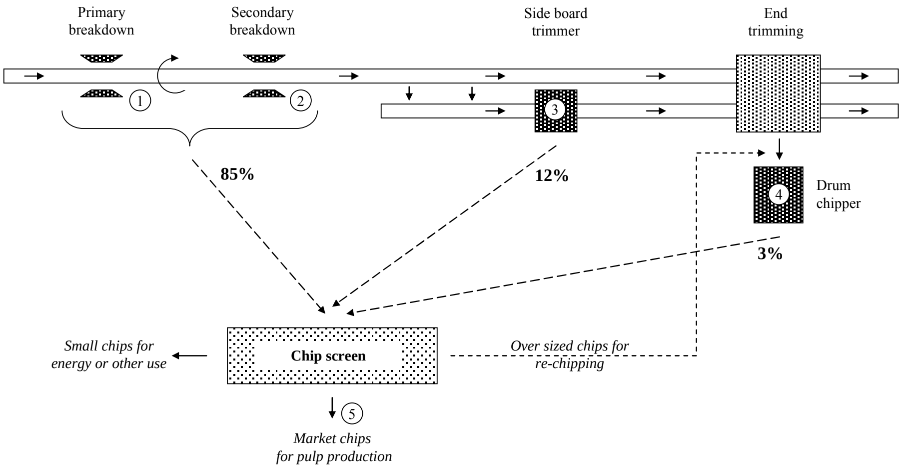

Fig. 10. Example of chip flows in a sawmill. 1-4 stands for chip producing machine centres and 5 for ready-to deliver market chips. The proportion of chip flow from different machine centres are displayed, based on estimations made by representatives of one sawmill.

Sawmills in Scandinavia are usually run on batches of logs sorted by diameter, for example five hours with 220-229 mm logs and then three hours with 130-154 mm logs, and so on. Some sawmills have double production lines, one for small dimension logs and another for larger logs.

The chip geometry depends on the type of chip producing machine centres, knife angles, anvil clearances, feeding speeds and rotational speeds. Frequency control systems of the chipping heads improve the control possibilities. Hedenberg, Lundquist & Bergman (1998) state that chips from chipping heads have narrow length distributions and the chips are often short (compared to a disc chipper, author’s addition). The length may be adjusted through changing the rotational speed of the heads. When the length increases the width and thickness also increase. This is supported by Helgesson (1998) who shows that there is a correlation between chip length and width. Chips from drum chippers are similar to chips from industrial roundwood disc chippers (Hedenberg, Lundquist & Bergman, 1998).

In most pulp mills, the logs are run through a process line specifically constructed for producing chips. The chipping is normally done by a disc chipper. In a disc chipper, the chip length can be controlled by the T-dimension, i.e. the distance between the knife and the disc wear plate (Hedenberg, Lundquist & Bergman, 1998). With an increase in the cutting angle (spout angle ε) in a disc chipper, the chips become thicker at the same length (Hartler, 1996).

Chip properties

The chip properties commonly used for setting requirements in Scandinavia are:

- Moisture content
- Bark content
- Chip dimensions, described according to screen classifications
- Discoloration
- Contaminations (i.e. stones, sand, plastic, metals etc)

"Since the early sixties, Sweden, Finland and Norway have been co-operating in the SCAN-test organization (Scandinavian Pulp, Paper and Board Testing Committee) to develop standards for the pulp and paper area. In the beginning, standards for pulp and paper testing were created. Since 1985, there is also a working group developing standards for wood and chip analysis. So far, eleven standards have been published (concerning chips, author's addition):

- SCAN-CM 39:94: Dry matter content
- SCAN-CM 40:94: Size distribution (later replaced by 40:01, author's addition)
- SCAN-CM 41:94: Sampling
- SCAN-CM 42:95: Bark content
- SCAN-CM 43:95: Basic density
- SCAN-CM 46:92: Bulk density
- SCAN-CM 47:92: Thickness and thickness distribution
- SCAN-CM 48:92: Length and length distribution (also applicable to width)
- SCAN-CM 50:94: Determination of acetone-soluble matter (later replaced by 49:03, author's addition)
- SCAN-CM 53:94: Wood content in the bark fraction
- SCAN-CM 59:96: Brightness

Of these standards, the first four are mostly used." (Hedenberg, 1999).

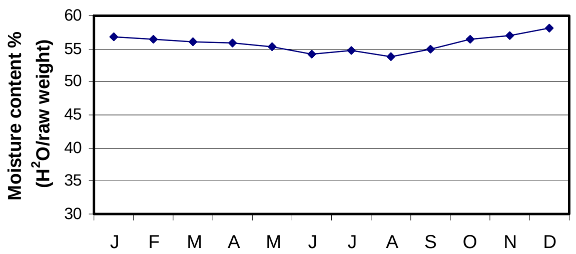

Fig. 11. Average moisture content in chip deliveries to Norske Skog's Norwegian mills in 2004.

Average chip moisture content fluctuates some throughout the year (Fig. 11). As most of the chips are produced from the outer part of the tree, they have high initial moisture content (see Fig. 3). The lead time from felling to sawmill gate for the timber, is probably close to that of pulpwood. One logistic difference is that sawlogs are normally stored for longer time at wood yards, but then the logs are normally irrigated during the dry season. The chips are seldom stored for longer than 3 days before being transported to pulp mills.

Bark, stuck to some chip pieces, creates problems as bark is hard to bleach. In newsprint and magazine paper, bark spots cause printability problems and thus may lead to reclamation of the paper. In cold periods it is harder to de-bark the sawlogs. The standard measurements taken regularly for quality control of 28 Norwegian and Swedish sawmills show a variation between the month of the highest bark content (March) with 0.64% bark to the month with the lowest (August) with 0.24%, (data from 2005).

Chip geometry is normally described by laboratory classifying methods, running chip samples through sets of screen plates with round-holes and slots (Fig. 12). The output of these measurements is normally presented as the dry weight content in different classes like; oversized chips, over-thick chips, accept chips, pin chips and fines. The result is used for communicating the desires of the pulp industry to sawmills, often using the screening results for pricing the chips.

In the sixties a laboratory screening system as showed in Fig. 12 (left) was widely used. In 1971 Edberg et al described a standard method, first called ‘Method 1’, then the ‘STFI pin chip method’ and later named SCAN-CM 40:94. In northern Sweden and Norway the new method was implemented, while in southern Sweden the ‘old method’ survived through to the 1990’s.

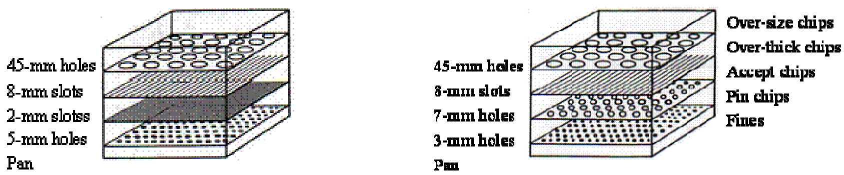

Fig. 12. Two laboratory classifying methods. ‘The old method’ and the standard screening method (Edberg, Engström & Hartler, 1971) that later became the SCAN-CM 40:94.

In Canada there has been a similar development, Hatton (1975a and b) described a new laboratory screening method, the WFPL-method. Earlier most mills in North America used round-hole screens – such as a William classifier – for chip-quality evaluations (Hatton, 1976), see Table 6.

Table 6. *The William classifier and the WFPL*

William	WFPL
1. 1-1/8-in. holes	1. 45-mm holes
2. 7/8-in. holes	2. 10-mm slots
3. 5/8-in. Holes	3. 7-mm holes
4. 3/8-in. holes	4. 3-mm holes
5. 3/16-in. Holes	5. Pan
6. Pan	

The Scandinavian SCAN-CM 40:94 and the Canadian WFPL divide a chip sample into similar classes. The only difference is that the WFPL permits somewhat thicker chips in the accept fraction.

Gradually the requirements on geometry have increased (Hedenberg, 2000) and SCAN-CM 40:94 was not appropriate with 85% accept chips. In Finland a 13 mm round-hole screen was added to divide the accept class into large and small accepts (this was an option in the SCAN-CM 40:94). The SCAN chip committee got instructions to find improved methods. There were discussions concerning both slots and round-hole screens but the work ended with the SCAN-CM 40:01 (Fig. 13 and 14) which obliged the 13 mm round-hole screen. The advantage with dividing the accept class is that it opens up for promoting a more narrow class, thereby steering toward more homogenous geometry.

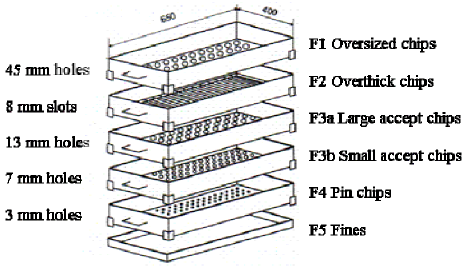

Fig. 13. SCAN-CM 40:01 (dimensions in mm).

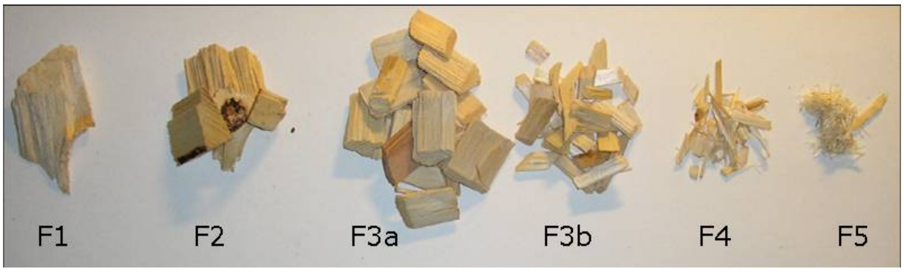

Fig. 14. The resulting classes of SCAN-CM 40:01 and SCAN-CM 40:01 classifying.

An optical system for measuring chip geometry was developed at STFI (Pettersson, Olsson & Lundquist, 1988). It measures the size distribution on a chip flow, according to the classes of the 'STFI pin chip method' and the thickness of the chip pieces. Iggesund Tools carried on the work and developed a device called the ScanChip, which measures chip lengths, widths and thicknesses (Bergman, 1998). The ScanChip also gives other output for example SCAN-CM 40:01 estimations, different slot classifying estimations and a calculated bulk density (called ID).

The three dimensions – length, width and thickness – may not be possible to define on all chip pieces. That is the case for chip pieces with shapes differing from the shape shown in Fig. 15, for example pin chips that are more or less matchstick-like or fines (sawdust).

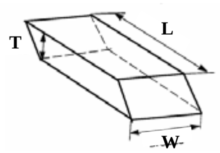

Fig. 15. Length (L), width (W) and thickness (T) of a chip piece (Tronstad, 1994).

The importance of chip geometry has been a source for discussion since one first started making pulp out of chips. Borlew and Miller (1970) give a good review of the work done in this field up to 1970, with focus on liquid penetration. Their conclusion is that a value of chip thickness of 3 mm is optimal for kraft pulping with alkaline liquids.

According to Broderick, Cacchione & Heroux (1998) very few studies have dealt with rates of diffusivity in all three directions; longitudinal, radial and tangential. They conclude that more studies are needed in this field so that a mathematical model can be derived to compute the proper impregnation time for chips of any wood species, given their dimensions and the cooking liquor used.

In the last decade some kraft pulp mills in Scandinavia have expressed a desire for larger and thicker chip pieces, the idea being that larger chip pieces gives faster liquid flow when digesting pulp and hence increased productivity of a given plant.

Hoekstra, Veal & Lee (1983) writes that for mechanical pulping "pulp of superior quality in both bonding and fiber length is obtainable with medium-sized chips of uniform distribution." This is supported by Brill (1985) who showed a clear relationship between tear index and uniformity expressed as content of accept-chips (F3). Eriksen et al (1981) makes the same conclusions and add that mixing fines or overlarge chips into homogenous chips gives a somewhat poorer pulp quality.

Bulk density is the weight amount chips per loose volume (kg dry weight per loosely stored m^3). In chemical pulping bulk density is important as it determines the quantity wood possible to load into a boiler – i.e. the production capacity. And the bulk density affects the transportation of chemicals and heat in the boiler, even circulation of boiling liquid is a condition for a uniform result. Bulk density is also assumed to be an important variable when refining chips in a TMP-process, the idea being that more uniform bulk density results in a more uniform chip flow into the TMP-process. The chip diagonal-to-thickness ratio (D/T) is almost linearly correlated with chip bulk density. An additional factor is the degree of geometrical heterogeneity of the chips. The mixing of over- and undersize chips into screened chips also increases bulk density (Edberg, Engström & Hartler, 1973). A third geometrical factor affecting bulk density is the shape of the chip pieces, irregular shaped chip pieces taking more room than more regular ones.

Requirements passed along the value chain

The requirements and expectations transmitted through the value chain are mainly related to:

- Costs. The products along the value chain have generally had an average price reduction in real prices of about two percent per year. This has been the case for newsprint, pulpwood in Norway, sawlogs in Norway and harvesting services in Norway for at least the last 40 years (Bjurulf 2005c). So each link in the value chain expects its suppliers to rationalize continuously.
- Delivery performance. Timely deliveries. Reliable plans and flexible planning.
- Quality. From now on the word quality is exclusively used for physical quality or more specific; Quality is 'clearly expressed property parameters'. I.e. the quality is bad when the raw material doesn't match expressed quality requirements. The quality requirements along the value chain do change over time. Generally more uniform products have been required. Some examples related to newsprint and magazine: These paper grades have had to become continuously stronger and more uniform the last 40 years to match the increasing speeds of the printing presses. Brightness properties and printing properties of the same products have also increased in significance to match the increased requirements on quality colour pictures in newspapers and magazines. Changes in requirements are transmitted back through the value chain to the physical requirements of the fiber raw material.
- Policies. Like most branches the forest industry has a pressure to implement sustainable management and social responsibility, often more extensive than legislation requirements. This pressure derives not only from the end-user, but is required from different stakeholders to many links in the chain. Important milestones in the development of environmental requirements for forestry are the UN environmental conference in Stockholm 1972, the Rio declaration on environment and development 1992 and the EU Pan-European Criteria and Indicators for Sustainable Forest Management in Europe initiated in the Helsinki agreement 1993 and the Lisbon conference 1998. Today P&P companies normally have policies for responsible purchasing. An example is the Norske Skog global wood purchasing policy which states "All wood used in Norske Skog's paper originates from sustainable managed forests" (Environmental report 2004, Norske Skog Supply & Logistics wood). Important tools are systems for SFM-certification (sustainable forest management). While the forest managers have SFM-tools, later links in the value chain have CoC-systems (chain of custody). A CoC certificate guarantees that claims of "certified wood" have been audited. The CoC systems have also recently developed requirements for responsible purchasing of the non-certified wood.

The main wood supply process of a pulp industry is mainly about securing the above mentioned requirements.

Cost benefit analysis

"The term cost benefit analysis is used frequently in business planning and decision support. However, the term itself has no precise definition beyond the idea that both positive and negative impacts are going to be summarized and then weighed against each other" (Schmidt, 2002). Schmidt also mentions three methods – return of interest (ROI), financial justification and total cost of ownership (TCO). All of these approaches attempt to predict the consequences of an action. They are primarily defined for investment projects and finding lifetime costs of acquiring and operating or changing something. Of the three methods, the TCO-approach is the one which has had the broadest applicability. TCO analysis originated with the Gartner Group (consultants in technology-related insight) in 1987, when the large difference between IT purchase price and total IT cost became known. The TCO-approach gave those who purchased and managed computing systems a tool to analyse total cost; purchase price, repairs, maintenance, upgrades, service and support, networking, security, user training and software licensing, among other expenses. Today TCO is applied in many contexts.

Since required properties of raw materials may affect both the purchase costs and the process costs and in some cases also the properties of the end-product, a cost benefit approach could be used in analysing raw material supply to a production unit. When purchasing market chips a bonus penalty system is normally included in the business agreement, with incentives for certain parameters. A cost benefit evaluation should be made when elaborating the quality system, balancing purchasing costs versus processing costs.

Objectives

Geometrical consistency of chips is desirable in both chemical and mechanical pulping. In chemical pulping the digestion of the chips is more controlled if the chip geometry is consistent. In mechanical pulping, more consistent chip geometry gives more stable refining. The bonus penalty systems have earlier had a lot of focus on restricting undesired fractions. These aspects are still important, but lately there has been expressed a wish for increased focus on consistency (Hedenberg, 2000).

The overall objective of this thesis was to evaluate the level of consistency of market chips and the possibilities to increase the consistency. The following studies were conducted.

Paper I. Different sawmills produce chips that differ in geometry. The geometry of chips may vary over time with equipment wear and maintenance cycles, and seasonal changes are also likely to affect the chips. The objective of this study was to analyse the dimensional consistency of market chips.

Paper II. In 2001 a new laboratory screening standard was introduced, SCAN-CM 40:01, where an extra screen was added. The purpose of the extra screen was to improve the possibility to promote consistent chips. The objective of this study was to analyze the result of screening with the new standard compared to that of the previous one and thereby give a starting point when formulating bonus penalty systems for the new standard.

Paper III. It is well known that chip dimensions can be controlled by changing the speed of chip cutting devices in the machine centres, adjusting knife positions and changing knife angles. However, the actual design of the sawmill machine centres, the surface quality requirements of the sawnwood, the screening operation and the re-chipping operation may limit the possibilities. The objective of this study was to test the control possibilities in practice.

Paper IV. Oversized chips are often screened out and re-chipped. This chip stream is often hidden since the oversized chips are normally chipped simultaneously with end-cuttings from board trimmings. The objective of this study was to investigate the properties of wood chips that are re-chipped.

Materials and methods

The introduction of this thesis starts with a wide description of wood and fibre properties, then it continues with a description of the Scandinavian wood market and wood requirements, and finally the concept of chip geometry is introduced. Swedish and Norwegian examples are mixed, taking the examples where the most reliable data was found.

Chip consistency (Paper I)

The aim of the study was to quantify the consistency of sawmill chips. The data materials consisted of spruce chip samples from five sawmills. The chip samples were randomly collected during the period August 2002 to March 2003, and the collection was done at the pulp mill gate. As a reference, data samples were taken from chips produced directly from roundwood at the pulp mill.

A sample consisted of about 10 litres of chips. The samples were analysed by an optical chip-scanner, the ScanChip-system from Iggesund Tools AB. The instrument measures chip length, width and thickness.

In this paper uniformity and consistency are distinguished from one another. Uniformity relates to a specific chip sample, and the more narrow or peaked a distribution is the more uniform. Consistency relates to a group of samples, for example the samples from a given sawmill over a period of time, the more similar the samples the higher the consistency.

Effect on chip size distribution when adding an extra screen in chip classification (Paper II)

The data materials consisted of chip samples from 12 sawmills. The samples were randomly taken, at pulp mill gate. Two sets of data were collected, the first to analyse the differences in classifying results between SCAN-CM 40:01 and SCAN CM 40:94 and the second to analyse levels and consistencies of the classes large and small accept chips, in the SCAN-CM 40:01 standard.

In the first data set two samples were taken from each sawmill. One of the samples was classified first according to SCAN-CM 40:94 and then according to SCAN-CM 40:01. The other sample was classified in the opposite order. The reason for this was to rule out potential errors associated with the order in which the samples were screened.

In the second data set 10 samples were taken per sawmill. The samples were only classified according to SCAN-CM 40:01.

In addition to the two data sets of the study, a reference data set has been used to see whether the study data sets were representative for a complete year. This data set consisted of chip classification results from all ordinary samples taken during one year (2002) for the 12 sawmills. These samples are taken as a standard procedure and are normally used for calculating dry weight contents and quality indexes.

Possibilities to control chip dimensions (Paper III)

In this study alterations were done in chip producing machine centres (marked 1-4 in Fig. 10). The dimensions of the chips were recorded before and after alterations.

The studies were performed at two sawmills, in the text referred to as sawmill A sawmill B respectively. Sawmill A has more modern chip producing machine centres than sawmill B. Before the study started sawmill A produced rather long chips and sawmill B rather short chips.

Two different studies were conducted. In the first study, the chipping head rotational speed in the two main breakdown groups at sawmill A was altered stepwise, starting with 425 rpm, and then the speed was increased in steps of 25 rpm up to 525 rpm. Two chip samples were taken for each rotational speed step. The study was done during one day and the sawlog dimensions were fixed to one class containing logs in the diameter interval of 306-320 mm, thereby obtaining rather standardized conditions.

In the second study, adjustments were made to different chip producing machine centres, with the aim to change chip dimensions – reducing the size of the chips from sawmill A, and increasing the chip size from sawmill B. For each sawmill three datasets were collected. A dataset comprises of chip samples taken over a period of about a month, the study was run from June to October. The datasets were separated by adjustments done to chip producing machine centres. The number of chip samples per dataset ranged from 16 to 30. The sawlog class was recorded.

In the first study the chip samples were collected after screening (point 5 in Fig. 10) and in the second study at pulp mill gate. An optical chip-scanner, the ScanChip from Iggesund Tools AB, was used to analyse the chip samples, i.e. the same method as used in Paper 1.

Re-chipped chips (Paper IV)

The study was performed at one sawmill. The aim was to evaluate properties of re-chipped chips.

Samples from ordinary operations were taken on two occasions, one when the mill was run on logs with diameters between 266 and 278 mm and one when run on log class 199-205 mm. In the first instance 8 samples where taken, hereafter referred to as pool 1, and in the second 10 samples, pool 2. The most common log class at the mill is 199-205 mm.

Chips were sampled from ordinary market chips, at sample point 1 in Fig. 16 (called pool 1), and from re-chipped chips at sample point 2 (called pool 2). When sampling was carried out at sample point 2, the flow of end-cuttings (marked 4) was turned off, to get only re-chipped chips in the samples.

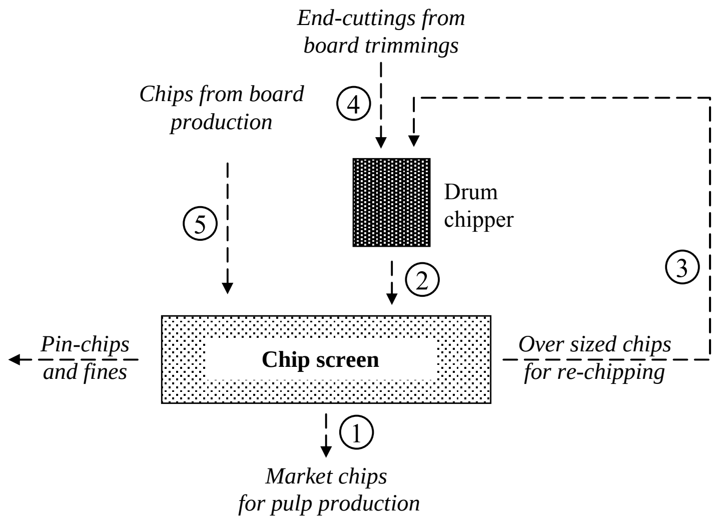

Fig. 16. Flow layout for the re-chipping process.

Each chip sample was classified according to SCAN-CM 40:01 for chip size distribution. Bark content was measured separately for the classes F1, F2, F3a, F3b and F4. The bark measurement of a sample was done according to the instructions of VMFQbera (wood measurement organisation Qbera), modified in the sense that the fractions were analysed separately instead of jointly. The size classes F1, F2 and F3a were separately classified for quality defects. The quality defect classes were related to knots, knot holes, irregular grain and compression wood.

A study covering re-chipping and screening of pure oversized chips was also performed, henceforth called pool 3. During this study the mill sawed log class 199-205. First a quantity of 500 litres of oversized chips was collected at sample point 3. Then the flow of chips from board production and the flow of end-cutting were turned off. The drum chipper was exclusively fed with oversized chips and seven samples were taken at sample point 1 and 2. For this study each sample was analysed according to SCAN-CM 40:01 for chip size distribution.

Results

Chip consistency (Paper I)

In this study, the dimensional consistencies of chips from a supplying population of sawmills to one pulp mill were studied during eight months. Fig. 17 displays the average length width and thickness distributions for the different sawmills in the study. Fig. 18 shows all samples from one of the sawmills, over the entire study period. It can be noted that the chip geometry from a single sawmill is more consistent over time than the consistency of chip geometry among sawmills in this study. Here consistency is defined as similarity between chip samples.

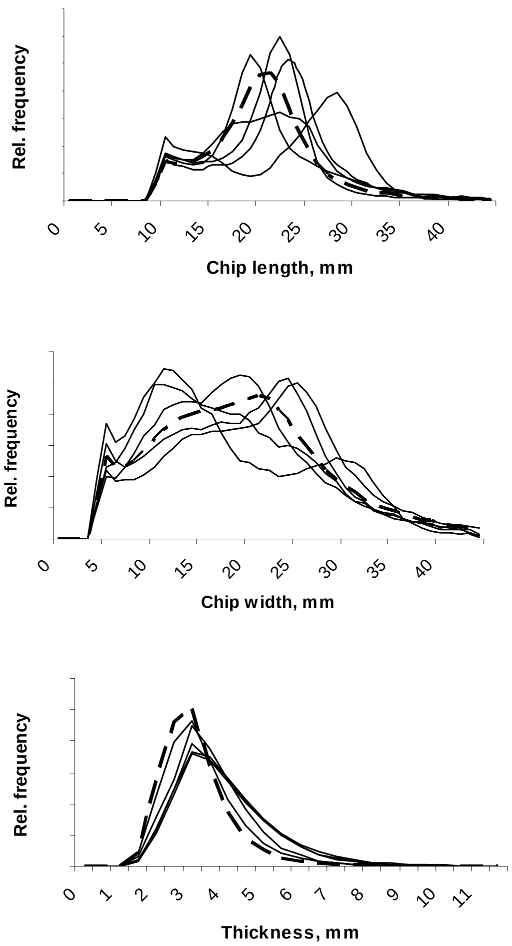

Fig. 17. Average length, width and thickness distributions for chips from five sawmills (thin lines) and the distribution for the roundwood chips produced at the pulp mill (thick broken line).

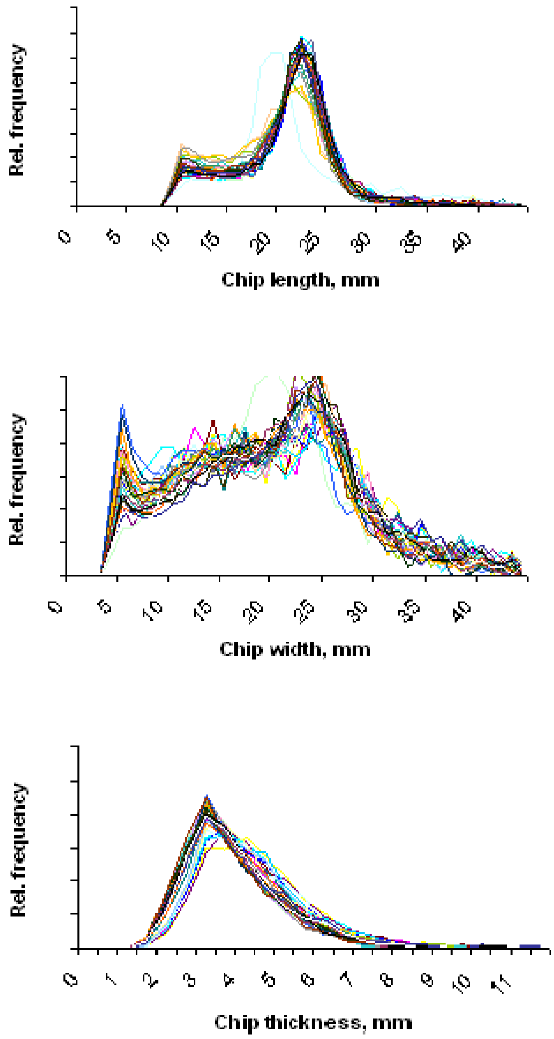

Fig. 18. Length, width and thickness distributions for sawmill B. 1 Aug – 31 March.

Effect on chip size distribution when adding an extra screen in chip classification (Paper II)

When screened according to the SCAN CM 40:94 method the accept class (F3) in average held 86%, and when screened according to the new method the accept amount increased with one percent, split into 65% F3a and 22% F3b (Table 7). The pin chip class (F4) decreased in average with 1.1% when screened according to the new method compared to the old one (Fig. 19 and Table 8).

The amount of large and small accept chips were noted to be relatively stable from a single sawmill (the pooled weighted standard deviation was 3.8% for large accepts and 3.1 % for small accepts). However there were large differences among sawmills in the proportion of these chip classes (59%-71% for large accepts and 14%-28% for small accepts).

Table 7. *Average chip classification distribution for data set 1 and 2 compared to one year average of the normal sample procedure from the 12 sawmills of the study*

	Average for a year, SCAN-CM 40:94 1377 samples	Weighted average, data set 1, SCAN-CM 40:94 24 samples	Weighted average, data set 1, SCAN-CM 40:01 24 samples	Weighted average, data set 2, SCAN-CM 40:01 120 samples
F1	0.1%	0.2%	0.2%	0.2%
F2	8.1%	9.5%	9.5%	8.5%
F3 (F3a, F3b)	85.6%	83.7%	(63.0%, 21.8%)	(64.8%, 21.6%)
F4	5.8%	6.2%	5.1%	4.6%
F5	0.4%	0.4%	0.4%	0.3%

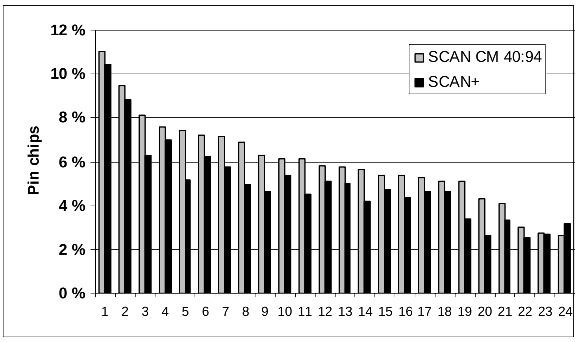

Fig. 19. Amount of pin chips for the 24 samples of data set 1, screened according to the two methods SCAN-CM 40:94 and SCAN-CM 40:01. The data is arranged from highest pin chip content to lowest.

Table 8. *The differences in screening result between the two methods. A positive value means that screening with SCAN-CM 40:01 has given a higher amount of that chip class. The F3 includes both F3a and F3b when screening according to SCAN-CM 40:01.*

	Weighted average difference	Number of samples	Weighted standard deviation	95% confidence interval	99% confidence interval
F1	0.0%	24	0.2%	-0.1% – 0.0%	-0.1% – 0.1%
F2	0.0%	24	0.7%	-0.3% – 0.3%	-0.4% – 0.4%
F3	1.1%	24	0.9%	0.7% – 1.5%	0.6% – 1.6%
F4	-1.1%	24	0.6%	-1.3% – -0.8%	-1.4% – -0.7%
F5	0.0%	24	0.0%	0.0% – 0.0%	0.0% – 0.0%

Possibilities to control chip dimensions (Paper III)

This paper consists of two separate studies. In the first study the dimensions of the screened chips decreased when the rotational speed of the chipping heads increased (Fig. 20). The correlation between rotational speed and chip length (r(rpm, chip length)) was 0.96, for width 0.62 and for thickness 0.90.

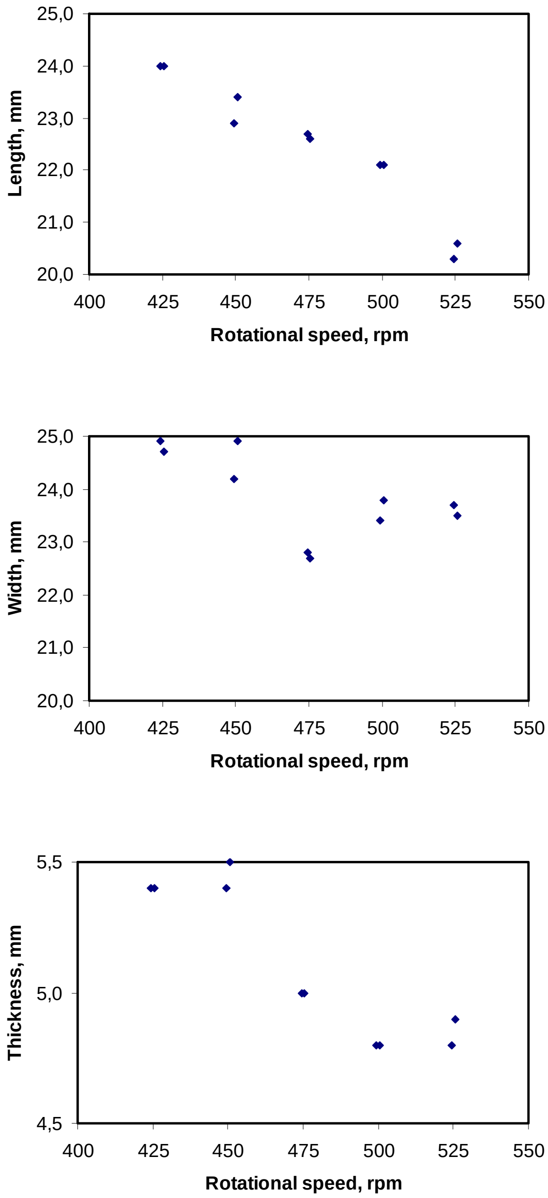

Fig. 20. Chip length, width and thickness for different speed of the chipping heads.

Table 9 and 10 displays the progress of the second study for sawmill A. A first dataset (dataset A1) was collected before any alterations were performed. Then the speed of the chipping heads in the two breakdown groups were increased by 100 rpm, at a constant log feed velocity (dataset A2). This resulted in smaller chips, in all three dimensional parameters. Finally the speed of the sideboard chippers was increased (dataset A3). Since the sideboard chippers did not have frequency control systems, this was done by changing pulleys. With this final adjustment the size of the chips decreased even more (Table 9 and Fig. 21).

Table 9. *Chip dimension statistics for the datasets from sawmill A*

	Length mm	Width Mm	Thickness mm
Dataset A1,			
Number of samples (n)	30	30	30
Average(average(x))	23.1	22.6	4.8
s(average(x))	0.6	1.1	0.3
Dataset A2			
Number of samples (n)	16	16	16
Average(average(x))	21.6	20.5	4.5
s(average(x))	0.7	1.5	0.2
Dataset A3,			
Number of samples (n)	17	17	17
Average(average(x))	20.2	19.4	4.3
s(average(x))	0.6	1.4	0.2
Level of significance Between A1 and A3	***	***	***

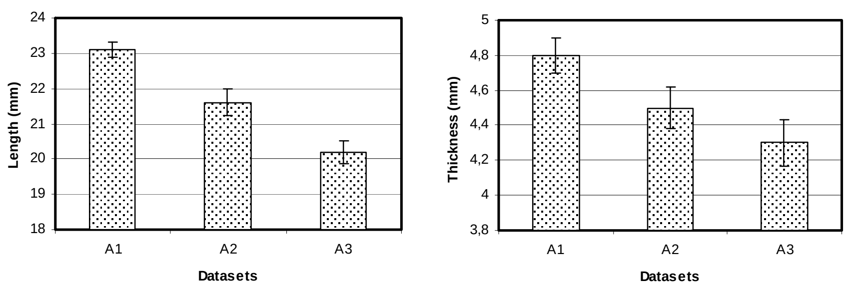

Fig. 21. Chip length and thickness for the datasets from sawmill A, 95% confidential intervals are marked.

At sawmill B the aim was to increase the size of the chip pieces. Table 10 displays the progress, dataset B1 was taken before any alteration of machine parameters were done. The positions of the knives of each disc in both breakdown centres were adjusted out, by 3 mm (data set B2). Then the speed of the chipping heads in the secondary breakdown centre was reduced, by changing pulleys (data set B3).

Table 10. *Chip dimension statistics for the datasets from sawmill B*

	Length mm	Width mm	Thickness mm
Dataset B1,			
Number of samples (n)	22	22	22
Average(average(x))	20.9	16.5	4.2
s(average(x))	1.1	1.3	0.1
Dataset B2			
Number of samples (n)	25	25	25
Average(average(x))	21.3	17.4	4.2
s(average(x))	0.6	1.7	0.1
Dataset B3,			
Number of samples (n)	20	20	20
Average(average(x))	22.0	17.6	4.1
s(average(x))	0.9	1.5	0.2
Level of significance between B1 and B3	**	**	

The aim with the second study at sawmill A was to produce shorter chips, and the measurement also showed that the screened market chips became smaller in all three dimensions. The hypothesis that the observed changes were due to random variation can be rejected with high probability (***). For the studies at sawmill B, with the aim of producing longer chips, the length and the width were changed significantly (**), while the thickness parameter remained almost unchanged.

Re-chipped chips (Paper IV)

In this study re-chipped oversize chips were compared to ordinary market chips. Fig. 22 displays chip size distribution for re-chipped chips compared to screened market chips.

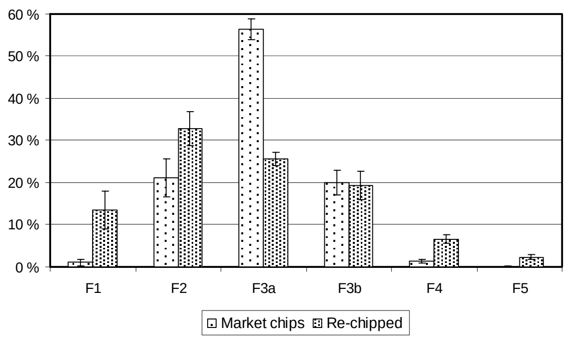

Fig. 22. Average chip size distribution. 95% confidential intervals are marked, pool 1.

Fig. 23 shows the differences in bark content between re-chipped oversized chips and ordinary market chips and Fig. 24 the differences in content of quality defected chips.

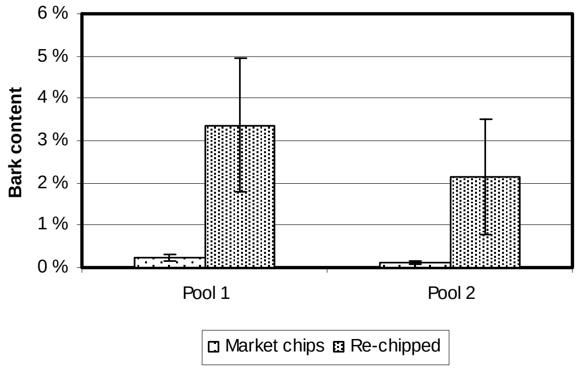

Fig. 23. Bark content, 95% confidential intervals are marked.

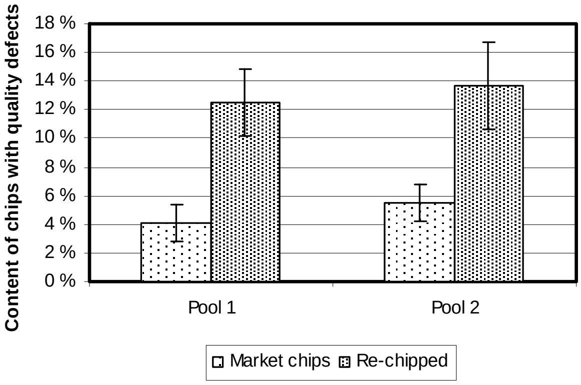

Fig. 24. Content of chips with quality defects, 95% confidential intervals are marked.

A study covering re-chipping and screening of pure oversized chips was also performed. Even though a lot of the F1 fraction was screened out, the main characteristics of the oversized chips remained after screening.

General discussion

General ideas on the optimizing of wood quality

The average size of a pulp mill has increased. During the last thirty years the number of pulp mills in Norway has been reduced from ca. 60 to ca. 10. At the same time the total production has increased. In 2004 some 40 percent of the raw material was imported (SSB, 2004). Today a pulp mill normally receives wood raw material from many different sources and of varied qualities. When choosing markets, raw material sources and quality requirements, a scientific management approach could be used: Find the raw material mix that minimizes costs, but still gives acceptable quality, reliable wood flow and satisfies environmental/social requirements. In this chapter two different ways to find desired quality level will be described. To my knowledge no one has yet formulated these axioms for raw material supply, though I regard these axioms as a basis for understanding the quality setting processes. The quality setting process involves both mill production functions and wood supply functions. There can be different quality requirements for different markets, even for raw material going to the same pulp mill, but the sum of all subsets should end up with minimized total costs of the paper produced.

The minimized wood cost approach. It could be expressed as "find the cheapest wood that can be used for production of sellable goods", i.e. find the raw material mix (geography and quality requirements) that:

- Minimizes mill gate cost (wood price + logistic costs to mill gate)
- Under the constraints:
  - Sufficient physical quality of the raw material for achieving runnable processes for production of pulp or paper, without an unacceptable degree of quality non-conformance paper
  - The mix adds up to a reliable and flexible wood flow that matches mill consumption
  - Environmental and social policies of the company

The minimized wood cost approach is too simplified to give an optimal solution because different raw materials give different production costs.

A more sophisticated approach would be: The minimized total cost approach. This more demanding approach is related to the TCO concept (total cost of ownership), and means that the effects different properties of the raw materials have on later links in the value chain are taken into account and expressed in monetary terms; i.e. find the raw material mix (geography and quality requirements) that:

- Minimizes wood mill gate costs + production costs in the mill + non-conformance paper costs
- Under the constraints:
  - The mix adds up to a reliable and flexible wood flow that matches mill consumption
  - Environmental and social policies of the company

The difficulty in implementing a strict "minimized total cost approach" is that the relationships between wood quality and production costs are complex (see Fig. 7 and 8) and the monetary relationships are seldom very well known. The actual quality setting processes are therefore somewhere between the two approaches above. In every day work the quality setting processes are more toward minimized wood costs, and in defining new quality regulations or outlining supply strategies more toward minimized total costs.

The quality setting is a part of a larger picture. In this thesis the total wood flow optimization field and the risk analysis needed for balancing minimized costs versus securing a "reliable and flexible wood flow" are not covered. Neither is the perspective widened to the effects caused by other markets, like paper markets, recovered paper markets and energy markets. Changes in these markets do affect the optimal behaviour on the wood market and the setting of optimal quality requirements. It is also important to bear in mind that the optimal behaviour changes over time.

According to my experiences a key issue when optimizing quality, is to have a view of the effects that a particular quality parameter has on the processes and on the quality of the end-product. The effects should be expressed in monetary terms. This information is critical for balancing purchase costs versus process costs and end-product quality loss costs. In some cases such analysis results in recommendations to increase quality requirements to reduce process costs. In other cases the analysis may result in recommendations to reduce quality, with the aim to broaden the raw material base and reduce total purchase cost.

Different aspects of chip geometry

There are two main issues that tend to cause chip geometry discussions to become complex. The first is that the relations between chip geometry and pulping processes are complex. Both in chemical and mechanical pulping many different variables are involved in the processes. The second issue is that chip geometry has many aspects and it is possible to have different focuses. One important aspect is the content of different fractions; oversize, over-thick, accept fractions, pin chips and fines etc. Especially the small size classes may cause problems in the mill processes (Eriksen et al, 1981). Another important aspect is of course the true dimensions of the chips and maybe especially thickness distribution curves, as thickness is important for liquor penetration (Borlew & Miller, 1970). Bulk density is a third relevant aspect with high relation to chip geometry (Edberg, Engström & Hartler, 1973), allthough bulk density is a somewhat complex parameter.

My experience is that different pulp mills have rather different views of optimal chip geometry (mill = persons representing the mill, a mode of expression). This may be explained by; firstly different pulping processes differs in chip requirements, secondly the actual mill layout often affects desired chip geometry, thirdly local wood and fibre properties vary and may interact with chip geometry which can affect the chip geometry desires and finally there are different theories and at one mill a certain theory may prevail, a theory which may not be the practice in another mill.

Based on personal experiences and examples from literature, I will give a few examples of different views on chip geometry: Recently several chemical pulp mills have desired rather large and thick chip pieces to get a faster liquid flow in the boiler and increase productivity. Many mechanical pulp mills express desire for rather thin chips to get an even liquid penetration. On the other hand there are examples of mills that desire thicker chips with the argument that it gives them a better refining. There are also mills wanting chips with high bulk density, arguing that, with their mill layout, this increases the flow into the refiner and hence increase productivity. Chemical mills generally want low pin chip content. The view on pin chips differs among mechanical pulping staff. Some have the view that the plug screw anyhow breaks chip pieces in the width dimension creating pin chips out of ordinary chips, while others say that the initial pin chips create problems in the plug screw and in the refining. However all agree that fines (sawdust) are not desired.

Chip geometry seems to be a subject for honest disagreement, but regardless of other views, it is a general understanding that consistency in chip geometry is desirable, for achieving stable pulping processes.

Since the aspects of chip geometry varies – undesired fractions, chip thickness, bulk density etc – also the optimal technique to monitor the chips varies. Below I will list and shortly discuss the standard possibilities:

- Classifying the chips in laboratory screening systems is a cost-efficient method that gives good control of the undesired, small size fractions; pin chips and fines. There are different standards differing in holes and slots size, with more or less focus on thickness. The adding of a fifth screen in the SCAN-CM standard has improved the possibilities to steer toward more consistent chips. Equipped with slot screens the method is efficient for monitoring chip thickness.
- Bulk density can be measured with the standard SCAN-CM 46:92. It may give valuable information to a pulp mill, but is probably unpractical to use as a steering parameter for sawmills. The reason is that the possibilities for a single sawmill to affect bulk density to a significant degree is rather limited, primarily because the basic density of the wood has high influence and the basic density is hardly possible to change, and secondly because the correlations between easily comprehended geometrical parameters and bulk density are somewhat complicated.
- Optical systems give detailed information on chip length, width and thickness and give good possibilities to work toward more consistent chips. A positive aspect of this method is that the length, width and thickness are parameters easy to comprehend for sawmills. Existing optical systems can simulate various laboratory classifying standards, with good result. Optical systems may also calculate a theoretical bulk density, but the results are not comparable to true bulk density mainly because data for true basic density is not available.

Conclusions

The geometry of chips from a single sawmill is almost as uniform as that of chips made by a pulp mill, and the geometry is relatively consistent over time (Paper I). However the geometry differs among sawmills and the resulting mix has low uniformity. There are obviously possibilities to increase total consistency by steering chips from different sawmills toward common geometrical targets.

In the cold period it was noted that the chips became marginally smaller (Paper I). This is also supported by the standard measurements taken regularly for quality control where rather small variations can be observed over the seasons, for instance the monthly average values for pin chips ranges from 4.5% in August to 5.5% in February (chip delivery data from 28 Norwegian and Swedish sawmills, 2005). However many sawmills express severe problems when the wood is frozen. One explanation for the difference between the experienced winter problems of sawmills and the relative mild effects noted on market chip geometry, is the screening out of undesired fractions, primarily the small ones, before delivery. The screened out fractions are used for other purposes than market chips. So the seasonal effects on the geometry of market chips were noted to be rather small, but there are other important chip parameters. During cold periods the bark content increases rather much.

In Paper II it was recorded that adding an extra 13 mm round-holes screen to the chip classification standard SCAN-CM 40:94 resulted in 1.1% lower recorded pin chip content. This part of the pin chip amount never passes through the accept trays but is retained with the accept fractions. The fines are not notably affected. The amount of large and small accept chips is relatively stable from a single sawmill. However there are large differences among sawmills in the proportion of these chip classes. These results should be taken into account when constructing bonus penalty system according to the new standard, SCAN-CM 40:01. The new standard improves the possibilities to steer toward consistent chips for a supplying population of sawmills.

Several studies have proved that it is possible to control chip dimensions by changing the speed of the chip cutting devices in machine centres, adjusting knife positions and changing knife angles. However these possibilities can be limited by the design of the chip producing machine centres and the surface quality requirements of the sawnwood. From Paper III it can be concluded that through methodical work with adjustments of the different chip producing machine centres, dimensions of the screened market chips can be controlled to a certain degree at sawmills. It was noted that frequency control systems of the chipping heads, largely increased the practical possibilities to control chip dimensions.

In Paper IV the re-chipping of oversized chips was evaluated, these chips contained high bark content, low content of accept chips (F3a and F3b) and rather high content of chips with quality defects (knots, grain irregularities etc). They also had shapes that differed from ordinary market chips, being longer and thinner.

Based on these observations, sawmills should analyse their re-chip flow when it comes to bark and accept chips content, and evaluate the monetary benefit of mixing this flow into ordinary market chips. The settings of the chippers and debarking devices should also be evaluated. The outcome of such an evaluation will vary among sawmills depending on raw material, technical equipment and bonus penalty system.

The studies have indicated good possibilities for sawmills to affect the geometry of the chips. This is also supported by observations over time from the chip market, many sawmills do adapt rather quickly to changes done to bonus penalty systems.

In the short run the introduction of the new SCAN-standard (SCAN CM 40:01) improves the possibilities for pulp mills to work actively with chip geometry consistency. But if there is a desire to get even better knowledge about the chip geometry, more sophisticated measurement systems have to be developed. Optical methods is a possibility, however the currently existing optical measurement systems are rather expensive.

Possible sources of error

During handling and transport, chips have a tendency to separate into layers with differences in chip size contents. This makes it a careful task to take chip samples. To minimize the risk of getting non-representative samples, representatives from the Norwegian wood measurement organization (NVM) made all the samling at pulp mill gate. Samples taken at sawmills were taken with great care by skilled individuals, in most cases by members of the chip geometry work group (of the Norske Skog Chip Geometry Project), according to elaborated procedures. In this way, errors made in the chip sampling have been reduced.

An optical chip-scanner, the ScanChip, was used to analyse the chip samples in two of the studies. The instrument measures the length, width and thickness of the chip pieces where the algorithms can detect the dimensions (Bergman, 1998; Petterson, Olsson & Lundquist, 1988). Since it is an optical instrument there are some aspects to take into consideration when comparing with mechanical measurements:

- The ScanChip detects only the geometric dimensions of about 45% of the chip pieces. Neither in the standard SCAN-CM 48:92 for analysing chip length and width distributions are all chip pieces measured, only those from the accept fractions (F3a and F3b), defined according to the standard SCAN-CM 40:01. This implies that there is a systematic difference compared with the SCAN norm. The fact that also the larger size classes are measured by the ScanChip indicates that length and width data from ScanChip measurements will be slightly higher than they would have been if the SCAN-CM 48:92 would have been used.
- If a chip piece has a bent shape the ScanChip will measure a thickness value that is too high, because it measures the length of the shadow. Bent

chip pieces were rarely observed and therefore estimated not to cause notable errors in the studies.

- When compared with the standard method SCAN-CM 47:92 for thickness distribution, the ScanChip measurement gives a lower average thickness. As the SCAN-CM 47:92 is a mechanical screening method, a small protruding part of a chip piece will make it stay above the grid, giving a higher average thickness than an optical measurement will give. This may imply that the ScanChip measurement gives a more relevant thickness value when discussing effects on pulping.
- With the ScanChip method, data is stored in more narrow classes than the standard methods SCAN-CM 48:92 and SCAN-CM 47:92 use, thereby providing more detailed information.

The choice of sawmills for Paper III is important for the results. We chose one sawmill with old machine centres and one with more modern. This was an intentional decision in order to get a wider range of variation.

In Paper IV the studies were conducted at only one sawmill, and during fairly short period of time. Even though the data base is small, the general conclusion on how re-chipping can effect chip quality is estimated to be valid.

Further research

One problem in implementing wood quality changes is that changes toward more desired qualities often implies costs, but the benefits (or saved costs) are seldom expressed in monetary terms since the relationship between wood/fiber properties and pulp/papermaking processes are not very well known. A better understanding of these relationships would be beneficial.

Development of the process of quality optimization would also be valuable. The communication between the production function in the mill and the supply function is important. There is a tendency for the production functions at the mills to want high quality, expensive raw material, while the supply functions purchase the cheapest raw material available that holds acceptable quality. Maybe there is need for better communication tools that invite these two critical functions to collaborate better on the best outcome?

In Paper IV the re-chipping cycle was studied. Further studies are recommended on the effects of screening and re-chipping. Also total chip flow analysis in sawmills would be valuable, quantifying flows and analysing chip properties from different sampling points within sawmills.

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