New value chains – Wood fractionation

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Summary

Pine logs with three different growth rates were delivered for fractionation and pulping studies from Metla's experimental plot. The logs were debarked and chipped at VTT and their average basic densities were determined. The maximum density and coarseness difference of the samples were 33 kg/ m^3 and 15 µg/m. Some sample logs were also analysed at STFI Packforsk with so called Silviscan method.

The size of chips was reduced to smaller than 2 mm in thickness in order to separate the early wood from latewood with a method developed at VTT. The resulting pin chips were then steamed and impregnated with water to remove air and to fill lumen and pores with water. Fractionation of chips was done using so called dense media fractionation method. Density of fractionating medium was adjusted according to the desired basic density of the fractions. Concentrated sodium sulphate solution was used as fractionating medium. Continuously operated prototype fractionation equipment was used for fractionation trials.

According to the results dense media fractionation can be used to increase basic density and coarseness difference of pin chips. The maximum basic density and coarseness difference were 150 kg/m^3 and respectively 50µg/m. The mechanical pulping trials revealed that density is very important raw material parameter in terms of energy consumption and pulp quality. The energy consumption difference of the fractions was 47 %. Fractionation increased also the surface roughness and density difference of paper samples.

Also standard cooking trials of the fractions were done, but only for medium growth rate fractions. Yield and brightness differences between fractions were measured, but more studies should be done to conclude the differences. Optimised cooking conditions of fractions should reveal larger fibre level differences.

As the next step, larger scale fractionation trials with commercial equipment followed by pilot scale mechanical and chemical pulping are proposed. Fractionation should also be considered as a multi-stage process. DM fractionation may be used to

- narrow the variation of raw material properties,
- reduce energy consumption and costs of fibre production,
- broaden the properties of fibre supply,
- deliver new product characteristics.

Confidentiality	Public

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Preface

This report is a part of the research project, which was carried out by VTT, KCL and Metla and financed by the Finnish Forest Cluster Ltd. The project is part of EffTech-program, started in 2008 and terminated in 2009.

This final report summarises the results of the fractionation and refining studies made at VTT. Research Professor Kari Edelmann was responsible of the VTT's subproject in New value chains -project. Research Professor Kari Edelmann, Senior Research Scientist Veli Seppänen and Research Scientist Juha Heikkinen are responsible in writing this report. Technician Jouko Aalto was responsible in planning and construction of the chip cleaving test rig, B.Sc. (Eng) Ismo Tiihonen, Research Assistant Jorma Ihalainen and Senior Research Scientist Veli Seppänen were responsible for carrying out the cleaving experiments, Research Assistant Jorma Ihalainen and Research Scientist Juha Heikkinen were responsible in dense media fractionation and thermo mechanical refining trials. Research Assistant Riitta Pöntynen was responsible in analysis at VTT.

Some properties of the wood samples were analysed at STFI Packforsk and results calculated at Metla. Researcher Harri Mäkinen from Metla was responsible for the calculations.

Chemical pulp cooking experiments were carried out at KCL from the materials delivered by VTT. Mrs Sari Liukkonen was responsible for the cooking experiments.

Jyväskylä, 12.8.2009

Authors

Contents

1 Introduction

Physical properties of wood vary due to soil conditions, climate conditions, genetic properties, silviculture and many other things. The variation of physical properties increases with the decreasing sample size; that is from mill scale to cutting area, stem and annual ring. The important properties that affect on pulping properties are basic density, fibre length distribution and moisture content. The content of extractives is supposed to affect on specific energy consumption (SEC) in refining (Reme 2000, p. 104). The extent of the variation of these properties is summarised in the next sections.

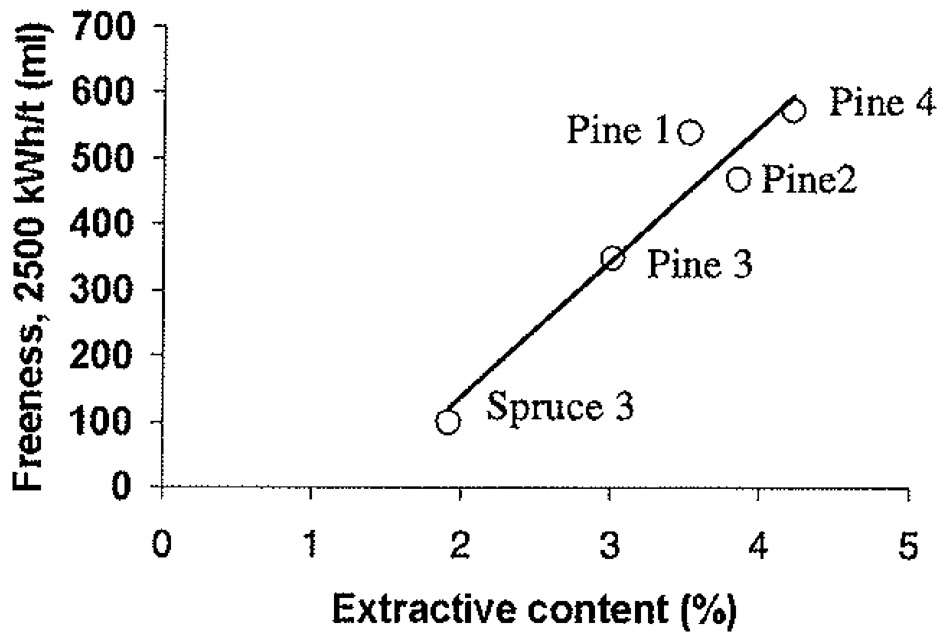

Figure 1. Effect of the extractives in refining (Reme 2000, p. 104).

1.1 Variation of basic density

The average basic densities of Scots pine saw mill and pulp chips used in some Finnish paper mills are presented in Figure 2. The range of variation is roughly 20 kg/m^3 by pulp chips and 40 kg/m^3 by saw mill chips.

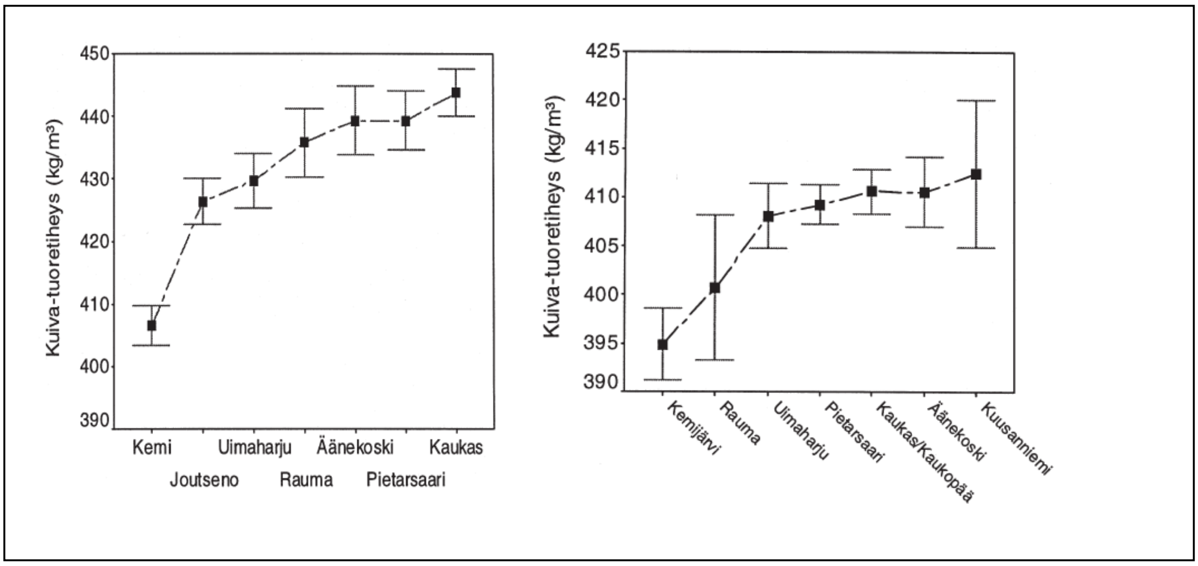

Figure 2. The average basic density (=kuivatuoretiheys) of Scots pine saw mill chips (left) and pulp wood (right) at confidence level 95 %. (Lindblad & Verkasalo 2001, p. 421).

The practical variation of basic density in wood samples is however much larger, as it can be seen in Figure 3. The average basic density for pulp wood chips is 406 kg/m^3 ranging from 390 to 420 kg/m^3. Saw mill chips have a little bit higher basic density values than pulp wood chips (Lindblad & Verkasalo 2001, p. 426).

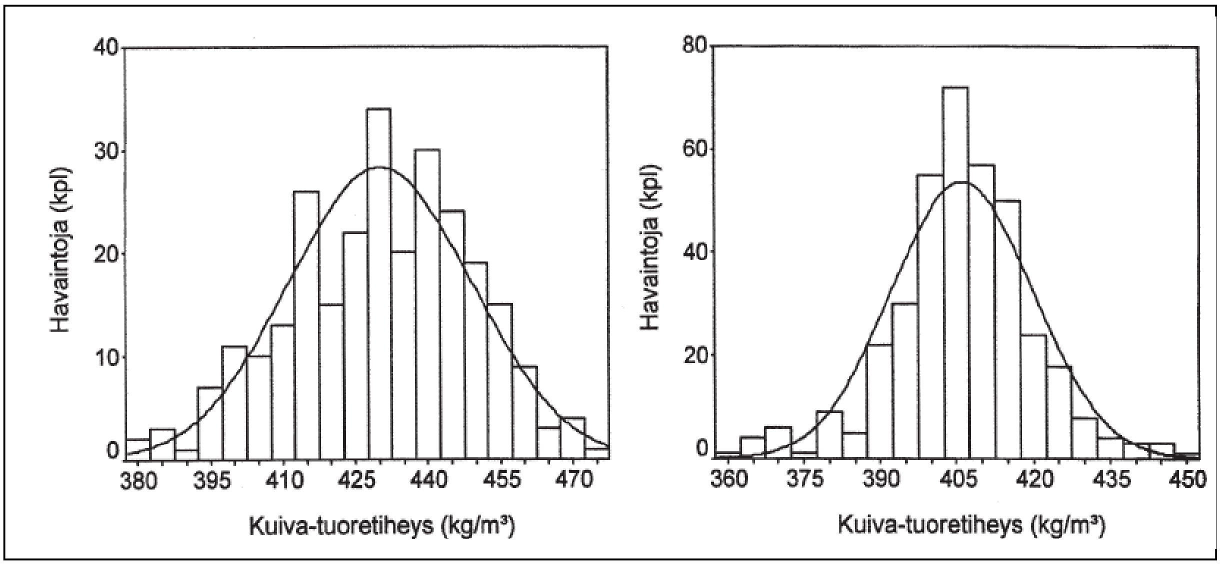

Figure 3. The basic density distribution of Scots pine saw mill chips (left) and pulp wood chips (right). (Havaintoja (kpl) =number of observations) (Lindblad & Verkasalo 2001, p. 416).

Within a stem, the basic density of wood changes both in radial and longitudinal directions, as shown in Figure 4 and 5.

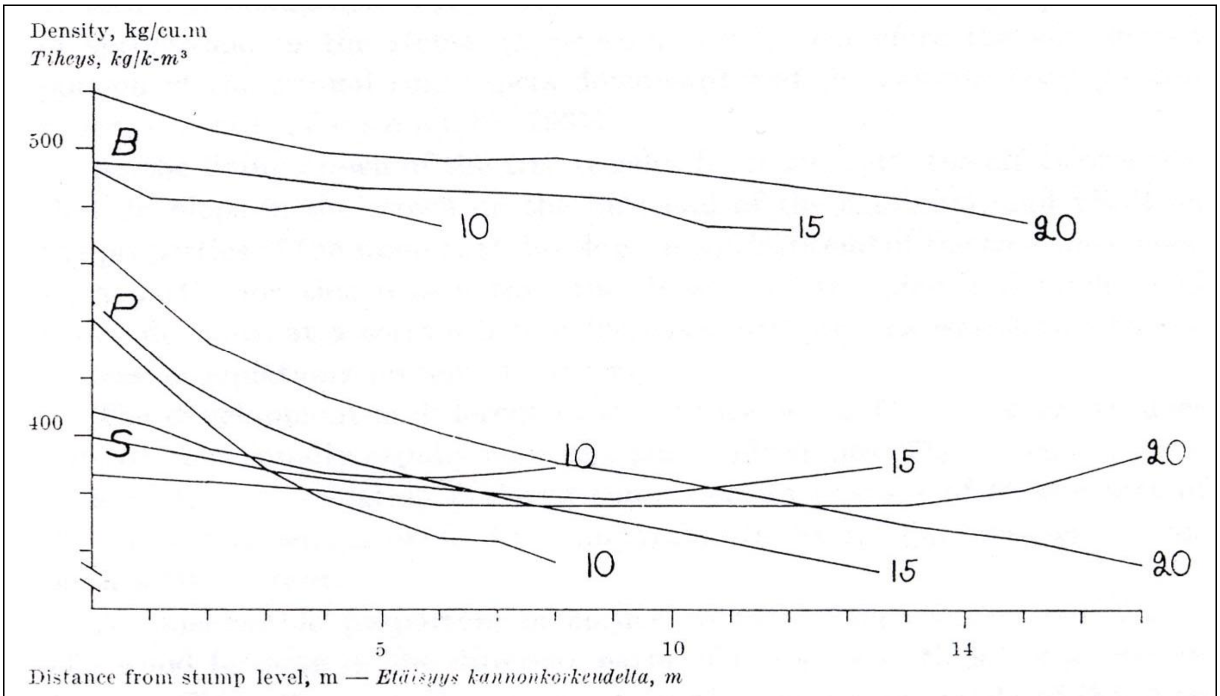

Figure 4. The variation pattern of average wood basic density in the longitudinal direction of the stem in Finland; Birch, Pine and Spruce (Hakkila 1966, p 41).

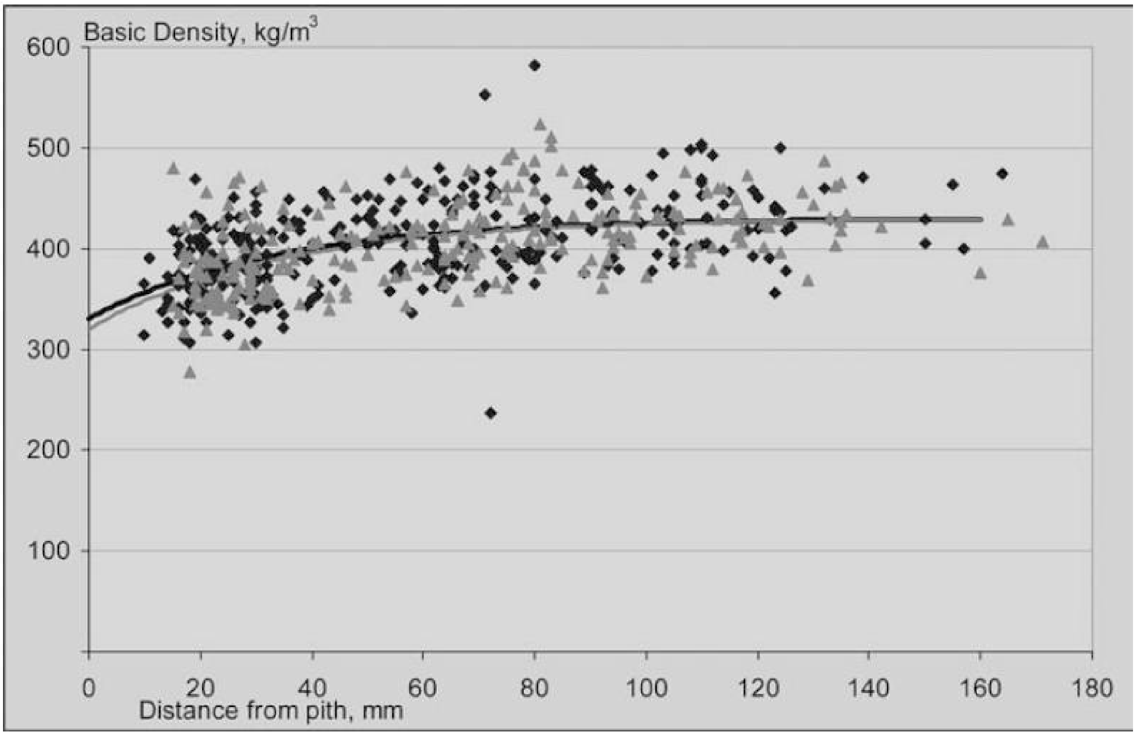

Figure 5. Basic density of wood (Scots pine) as a function of distance from pith in dataset 1 (diamonds) and dataset 2 (triangles) (Kärenlampi & Riekkinen 2004, p. 467).

As the result of the variation pattern of wood basic density, raw material and fibre properties of pine vary in a very large range depending on the age and growth rate of the tree and on the location of a wood sample within a stem.

The growth rate, a factor that determines the mechanical strength properties of wood, can easily be determined visually from a cross section of a tree. The density of growth rings is dependent on growth conditions. At microscopic level, the growth ring consists of large, thin cell wall fibres (early wood) and smaller, thick cell wall fibres (latewood). In average, the amount of latewood fibre in pine in top wood is about 21 % (Rikala 2003, p 64).

1.2 Variation of fibre length

The fibre length increases from pith to sap wood and decreases from butt to top. It is interesting to find out that old sapwood have longer fibre length compared with sapwood of younger final cutting or second thinning trees.

In average slowly grown wood has longer fibre length than fast grown wood.

Fibre length correlates strongly with fibre coarseness (Sirviö & Kärenlampi 1996, p 19).

1.3 Variation of moisture content

Inside a stem, moisture content increases from butt to top, Figure 6. Moisture content is much higher in sapwood (60 % wet basis) than in heart wood (25 %). Moisture content of wood may also change due to varying storage times of stems and chips. Moisture content of wood varies also with season; in summer time around 39 % and at Christmas around 50 %. These moisture content variations all together make problems in sorting of logs or chips according to basic density.

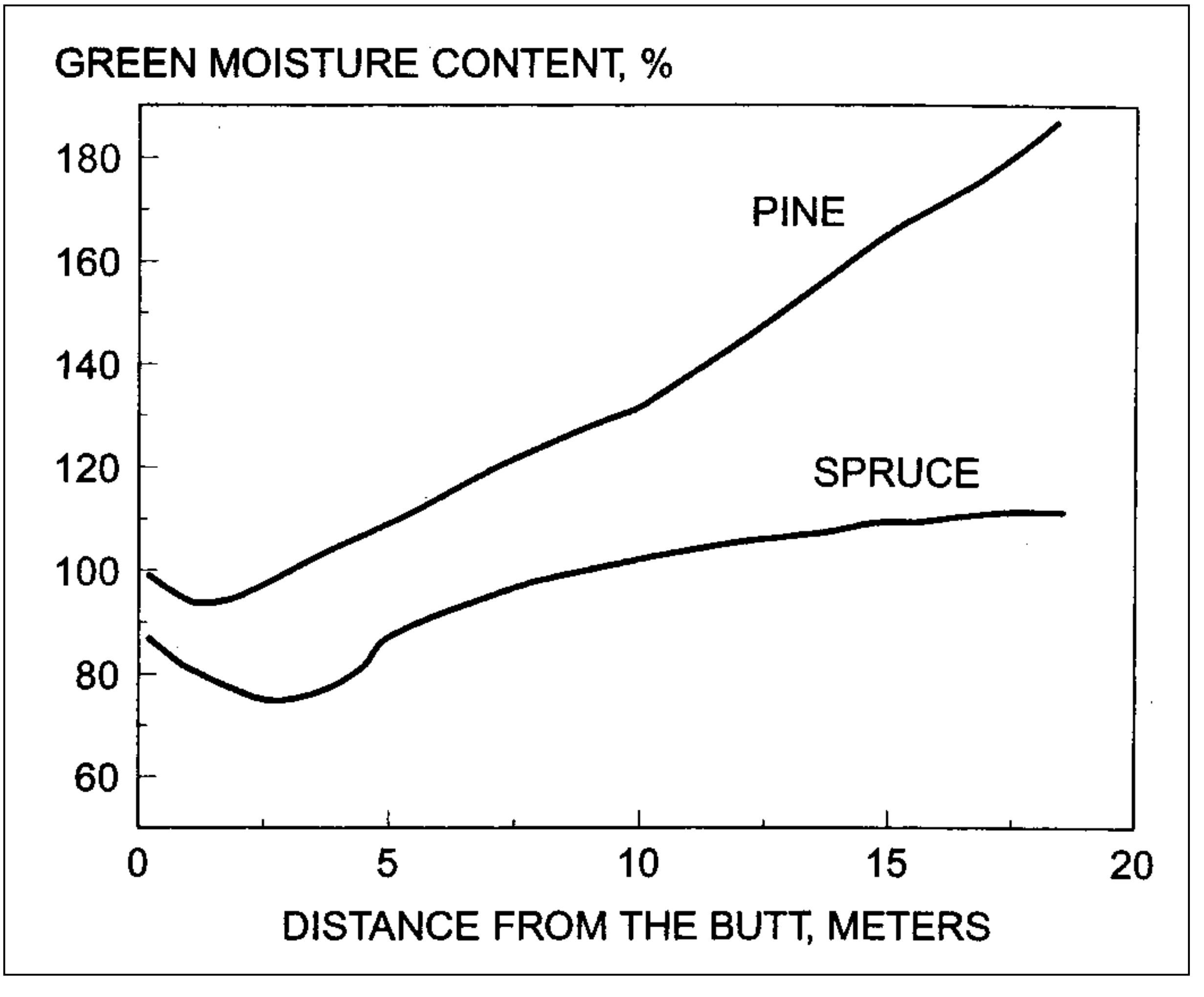

Figure 6. Variation in the average green moisture content (dry Basis) along the stem height in Norway spruce and Scots pine (Tyrväinen 1995, p 29).

1.4 Effect of the wood material on the properties of mechanical pulps

Correlation between wood properties and TMP pulp properties has been widely studied (Tyrväinen 1995, Reme 2000, Liukkonen & Sirviö 2006, Hartler 1985). Hartler has concluded that TMP -pulp from high basic density wood results in lower tensile index than from lower basic density wood, Figure 7.

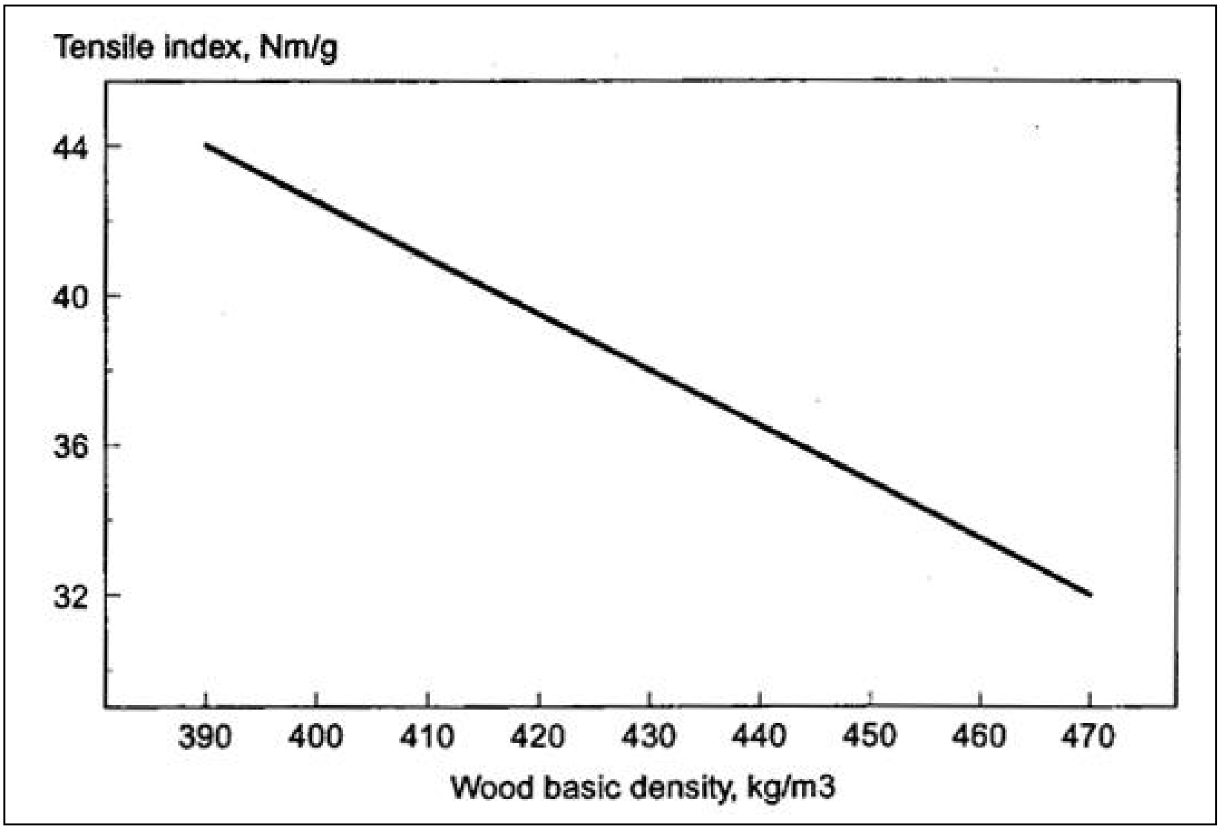

Figure 7. Effect of wood density on tensile index of spruce TMP according to Hartler (1985). All tensile index values are at 100 ml freeness (CSF) level.

The significance of early and latewood fibres in papermaking has been studied by sorting stem wood according to its diameter and growth rate. Papermaking properties and energy consumption differences between early wood rich juvenile and latewood rich mature wood are significant. In refining, mature wood (longer and thicker wall fibres) absorbs energy more easily than forest thinning wood (shorter and thinner wall fibres) (Tyrväinen 1995, Nyblom 1979 and Hartler 1985).

Delamination (or peeling of the outer layers) of rigid fibres is very important for paper quality, as fibres having cell wall thickness greater than 4 µm do not collapse in the papermaking process (Forseth 1997). Thick wall fibres will also increase roughness of paper when treated with water (Hallamaa et al. 23.6.1998). Tensile index of the long fibre fraction can be increased 100% by reducing the amount of thick wall fibres from 10 to 4 % (Koljonen & Heikkurinen 1995).

2 Goal

The objective of this study was to produce fractions with large basic density difference though use of dense media fractionation method. The further objectives were to use these fractions in mechanical and chemical pulping and to analyse the respective fibre properties and to determine the potential of fractionation in saving energy and chemicals. Lab scale fractionation methods and pine samples with different growth rates were used in the study.

3 Description

3.1 Devices

Knife mill was used to cleave pulp chips into chips thinner than 2 mm. The cleaving separates rather effectively early wood (EW) from latewood (LW). A continuously operated process was set up to maximise the separation efficiency of EW, Figure 8.

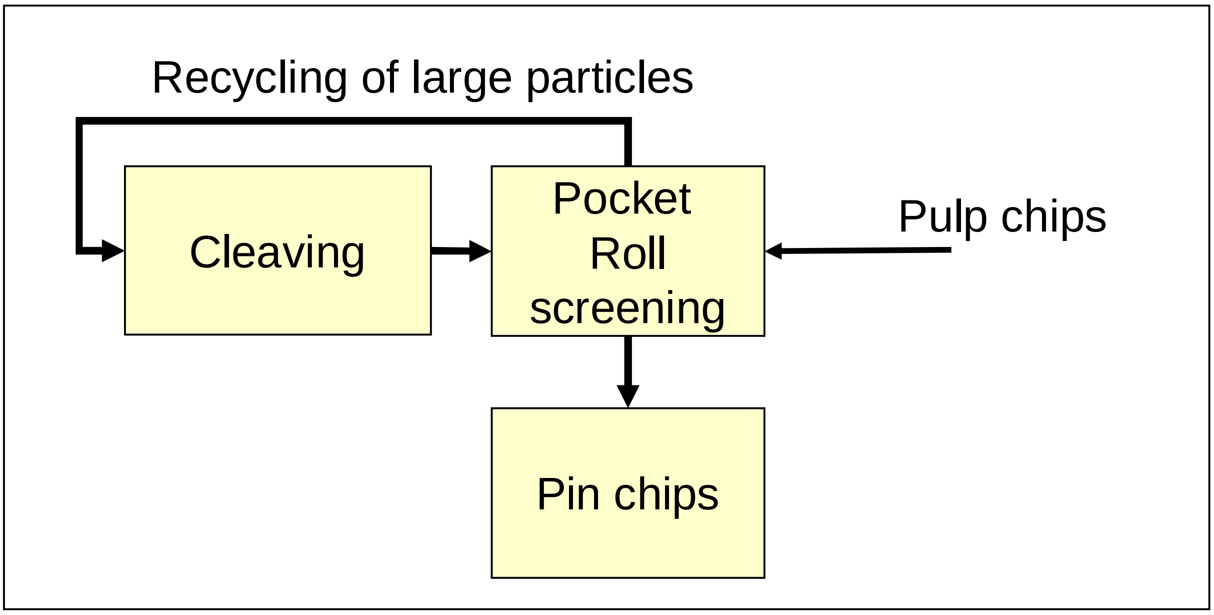

Figure 8. Principle of the pin chip process.

The equipment consisted of a feeder pin, belt conveyors, knife mill and Pocket Roll screen, Figure 9.

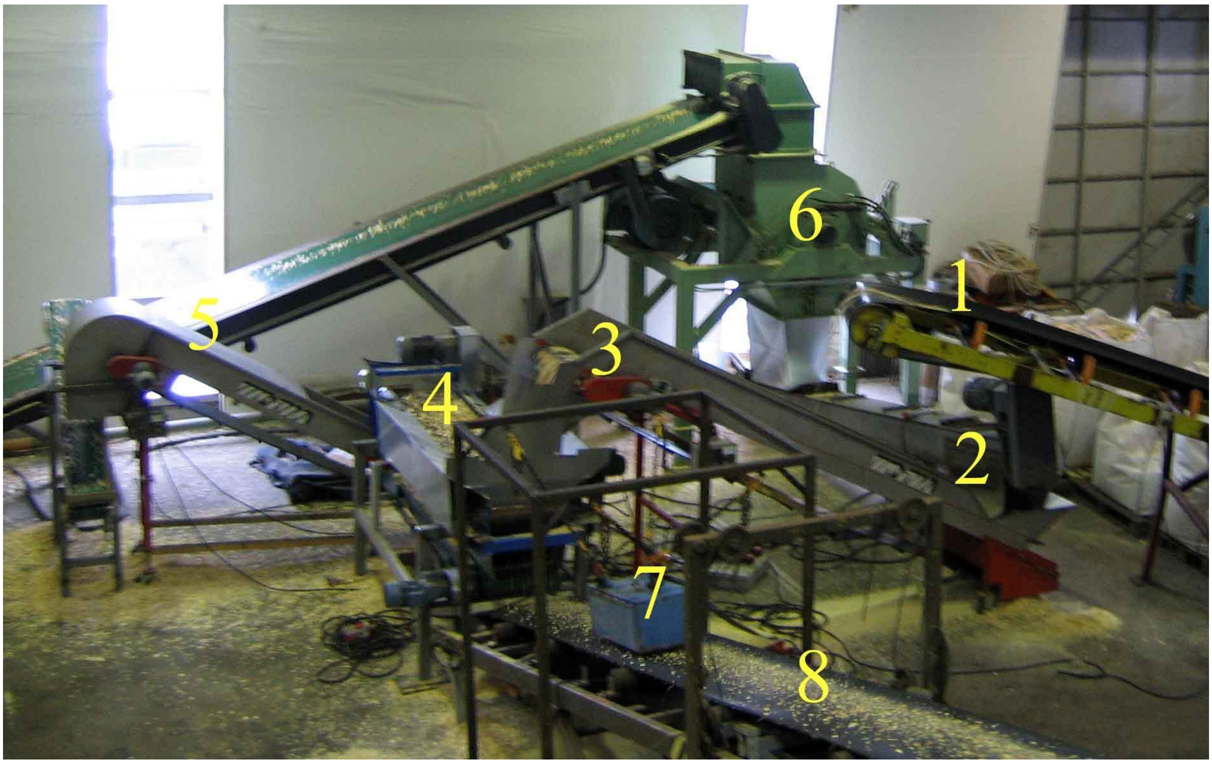

Figure 9. Continuous cleaving and screening process for pulp chips. 1 = feeding of pulp chips, 2 = conveyor of cleaved chips, 3 = feeding pulp chips and cleaved chips on screen, 4 = Pocket Roll screen, 5 =conveyor of oversize chips, 6 = knife-mill, 7 =magnet, 8 =conveyor of accepted pin chips.

After separation of EW from wood chips, the target was to find out how EW pin chips could be separated into its own fraction as pure as possible. So called dense media fractionation method was used, Figure 10. The equipment is shown in the Figure 11.

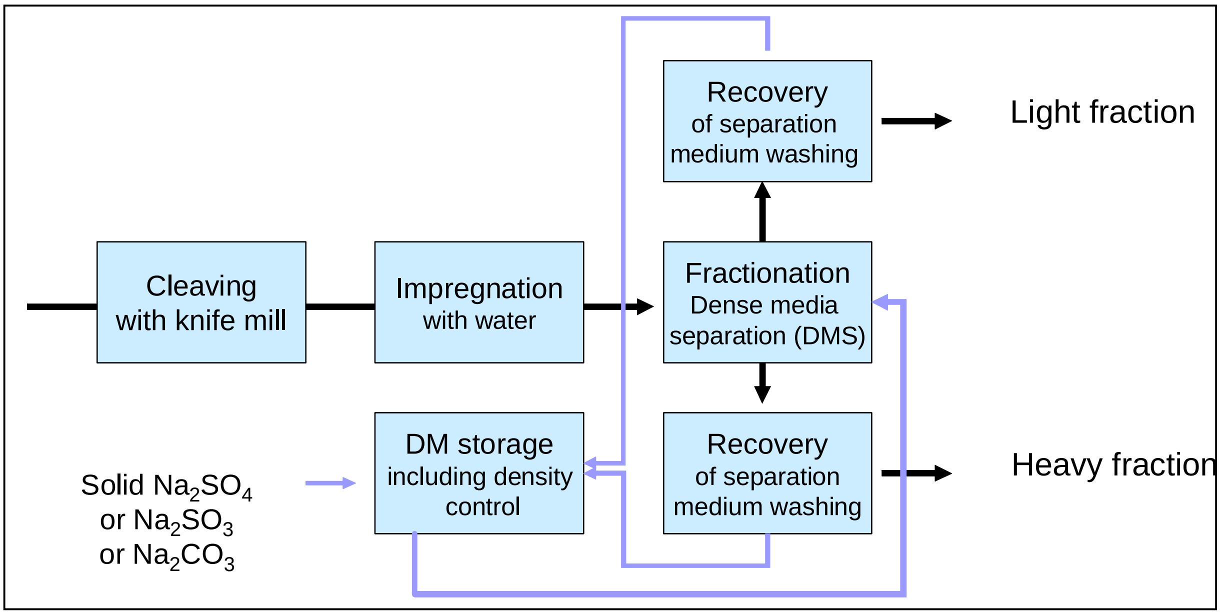

Figure 10. Principle of the EW/LW fractionation concept.

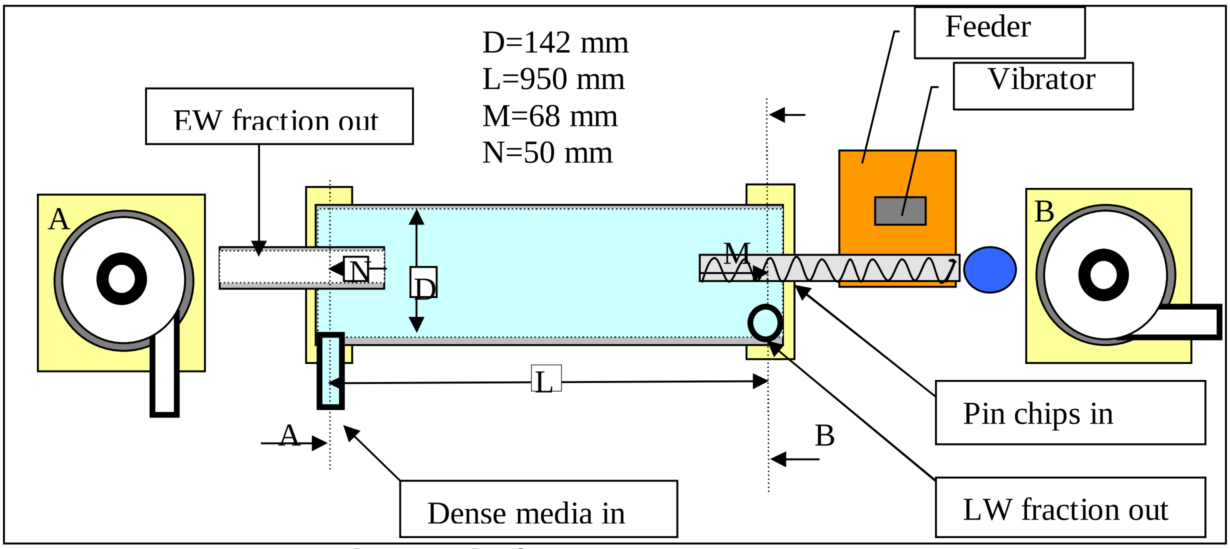

Figure 11. Continuous dense media fractionation.

The pin chips were refined by VTT's wing refiner, Figure12.

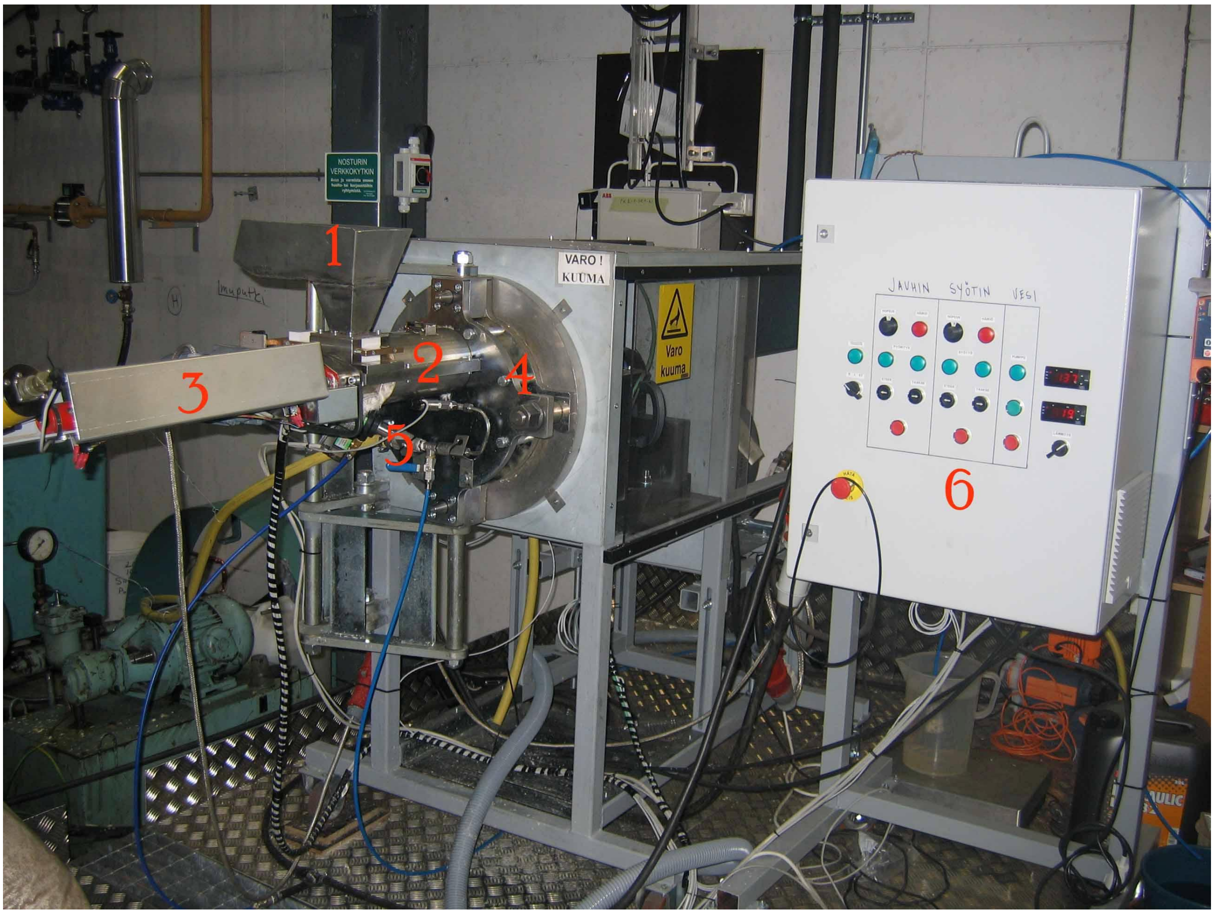

Figure 12. Wing refiner; 1 = Feeding channel, 2 = pre-heating of chips, 3 = feeding piston, 4 = refiner, 5 =pressure control, 6 =control panel.

3.2 Samples

Metla (Forest Research Institute) provided pine logs with three different growth rates. Top wood samples of 150 – 60 mm in diameter were used in the trials.

4 Limitations

Only three basic density classes were used in the studies. Each basic density class consisted of pulp wood parts of two stems.

Fractionation trials have been done in laboratory scale using single stage fractionation. The results have been used in a way that may be achieved through two stage fractionation.

Mechanical and chemical pulping trials have been done batch-wise in laboratory scale.

5 Methods

5.1 Characterization of wood samples

The sample trees were characterized by measuring

- the breast height diameter,
- height of the tree,
- the height to diameter 6 cm,
- branch diameter
- living branch or dead,
- number of annual rings of the sample logs,
- diameter of the sample logs,
- annual rings of each cut,
- basic densities of sample discs of each log,
- bark content,
- moisture content of bark and wood.

The fibre properties of the sample discs were analysed by Silviscan, an automated scanning x-ray micro-densitometer/image analyser, (Evans et al. 1993). In Figure 13, we can see that coarseness values are rather similar within annual rings, but density has large variation. Density is low in the beginning of the growth season and high at the end of growth season.

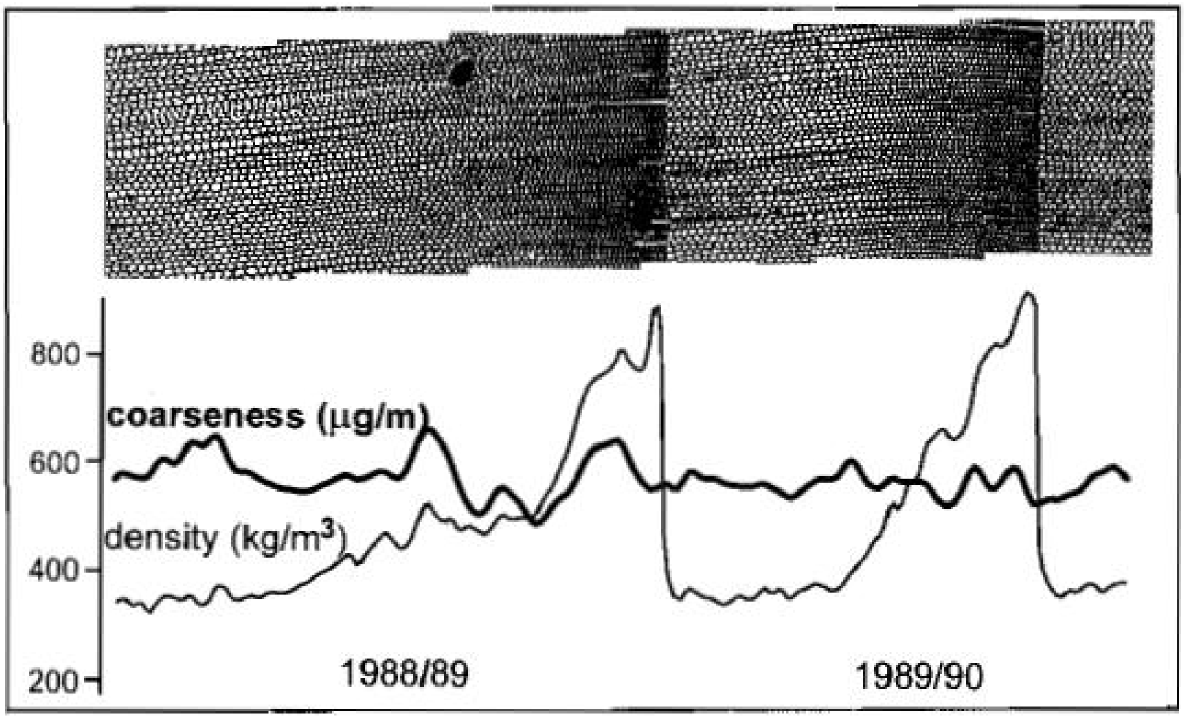

Figure 13. Example of Silviscan measurement (Evans et al. 1993).

5.2 Fractionation of wood

So called dense media fractionation technique was used to fractionate wood raw material. DM fractionation has been used in industrial scale to fractionate coal and plastics. The first step is to separate early wood and latewood into separate particles. Because the annual rings in pine are only 1-3 mm in thickness, the particles have to be smaller in thickness than the annual rings.

The sample logs were debarked manually, chipped with TT1000TU disc chipper, cleaved with knife mill and screened with modified Pocket Roll screen for pin chips.

To get right density differences for early wood pin chips and latewood pin chips the lumens have to be filled with water. Therefore the pin chips were steamed and impregnated with water.

Steaming of pin chips was done in a pressure vessel at 104 ˚C temperature and in 0.4 bar pressure for 15 minutes. After steaming, warm water (50˚C/0.3 bar) was fed trough the vessel for 15 minutes. After impregnation the pin chips were stored in plastic bags, at 5 ˚C for further use. The impregnated and stored pin chips were laid 30 minutes in water before fractionation, if the storage time is more than 6 hours.

Stationary preliminary fractionation trials with different dense media were done in 1.5 litre static beaker using concentrated Na_2SO_4 solution. Density of the solution was chosen in a way that the pin chips separate into floating and sinking fractions after mixing the impregnated pin chips into the medium. After 2 minutes of mixing photograph was taken and fractions were collected and washed with pure water to remove traces of saline solution and then weighted with respect to their yields. Yield of the floating fraction was dependent on the density of the medium.

Continuously operated lab-scale fractionation equipment was used for fractionation trials, Figure 11. The suitable operation parameters were studied with pre-studies:

- dense media density levels 1075, 1115 and 1160 kg/m^3
- slope of fractionator 20˚
- velocity of dense media 2,67 litres/s
- temperature of dense media 35–40 ˚C
- fractionation capacity 20 kg (DS)/h.

The exact values of each trial point are presented in the result Table 1.

The following properties of the fractions and fed pin chips were measured:

- basic density
- fibre properties
- particle length and width distribution
- refining properties

SEC (Specific Energy Consumption)/t
RRm
fibre properties of accepted fractions
paper properties of accepted fractions

6 Results

All experimental results are shown in the appendix 1 and only main results are presented in the following text.

6.1 Characterisation of wood samples

The sample trees were harvested from two different experiments and from tree different experimental plots. The trees 126 and 235 were fast grown, trees 35 and 72 medium grown and trees 21 and 129 slowly grown.

6.2 Fractionation of wood

Before fractionation, the pulp chips were processed into pin chips. The particle thickness was analysed by mechanical screen and the distributions are presented in the Figure 14. Less than 8 % of the pin chips are thicker than 2 mm. 42–50 % belongs to classes 0–1 mm and 1–2 mm in thickness. Only small differences, but not significant, appear in different growth rate classes.

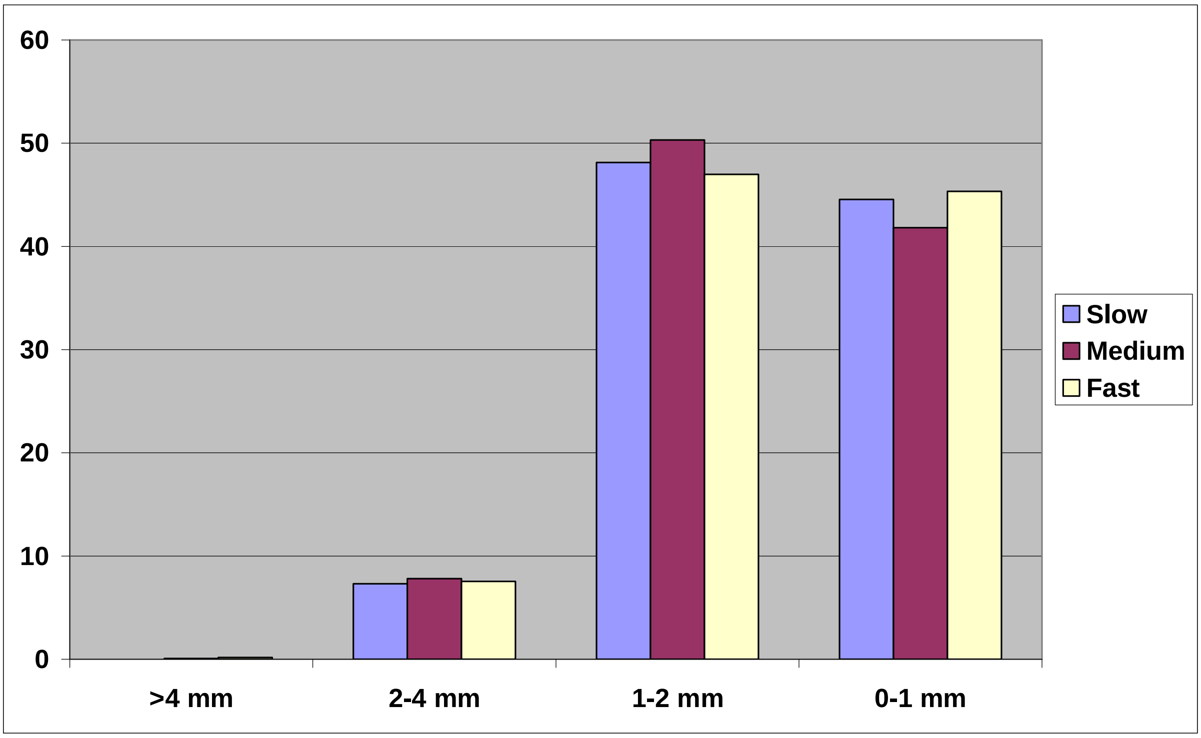

Figure 14. Particle thickness distribution of the pin chips.

Another particle size measurement was done by image analysis. The length and width distributions of pin chips are presented in Figures 15-17. Original pin chips were rather similar in length and width. The greatest difference was noticed between latewood fraction from slowly grown wood and early wood fraction from fast grown wood. Early wood fractions are longer and thicker than latewood fractions.

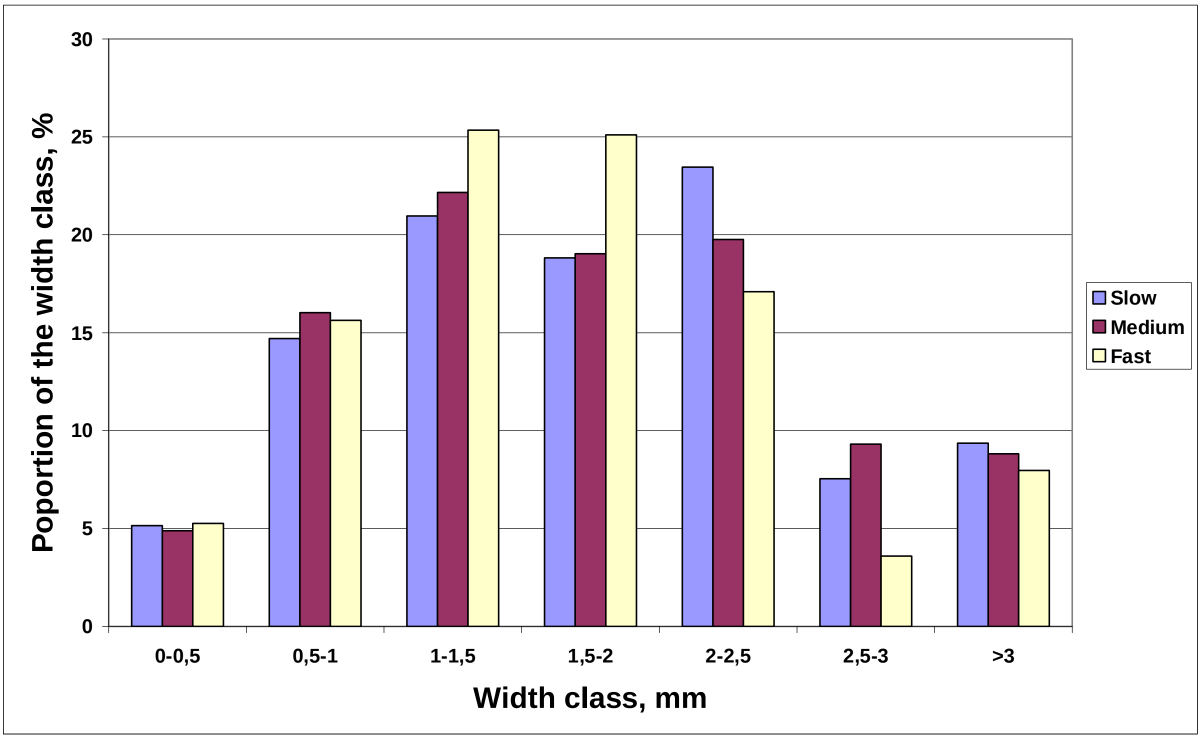

Figure 15. Width of unfractionated pin chips.

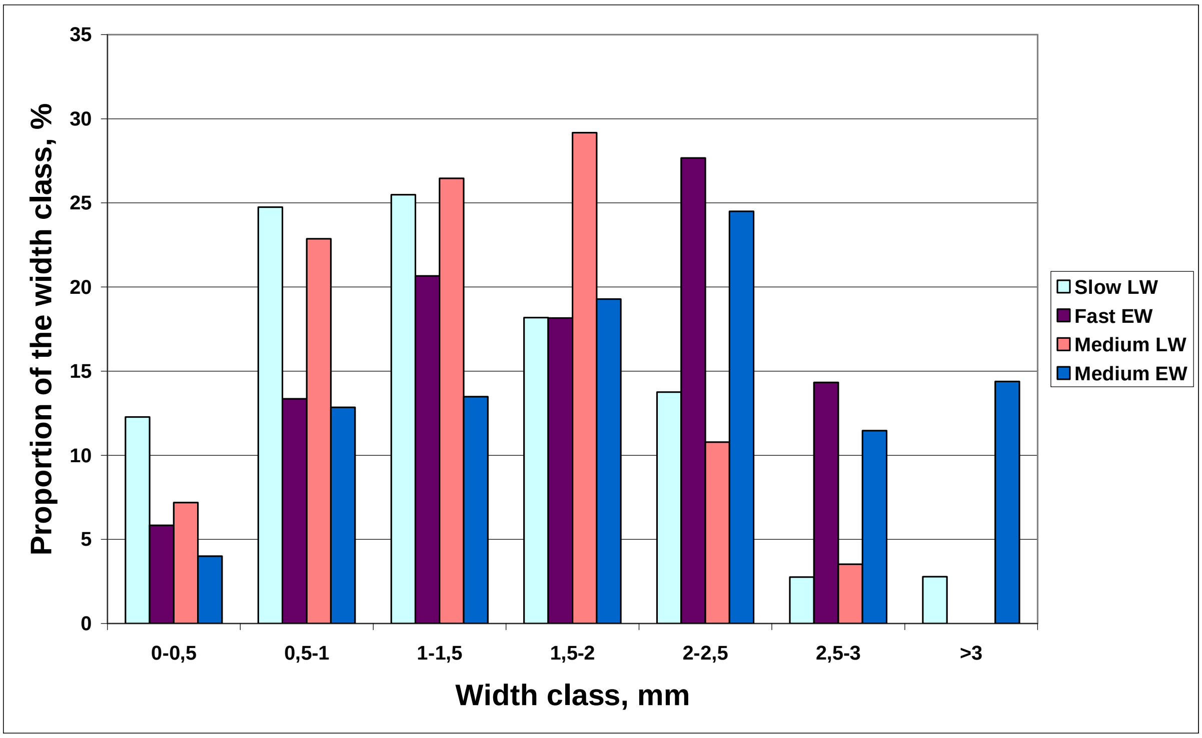

Figure 16. Width of fractionated pin chips.

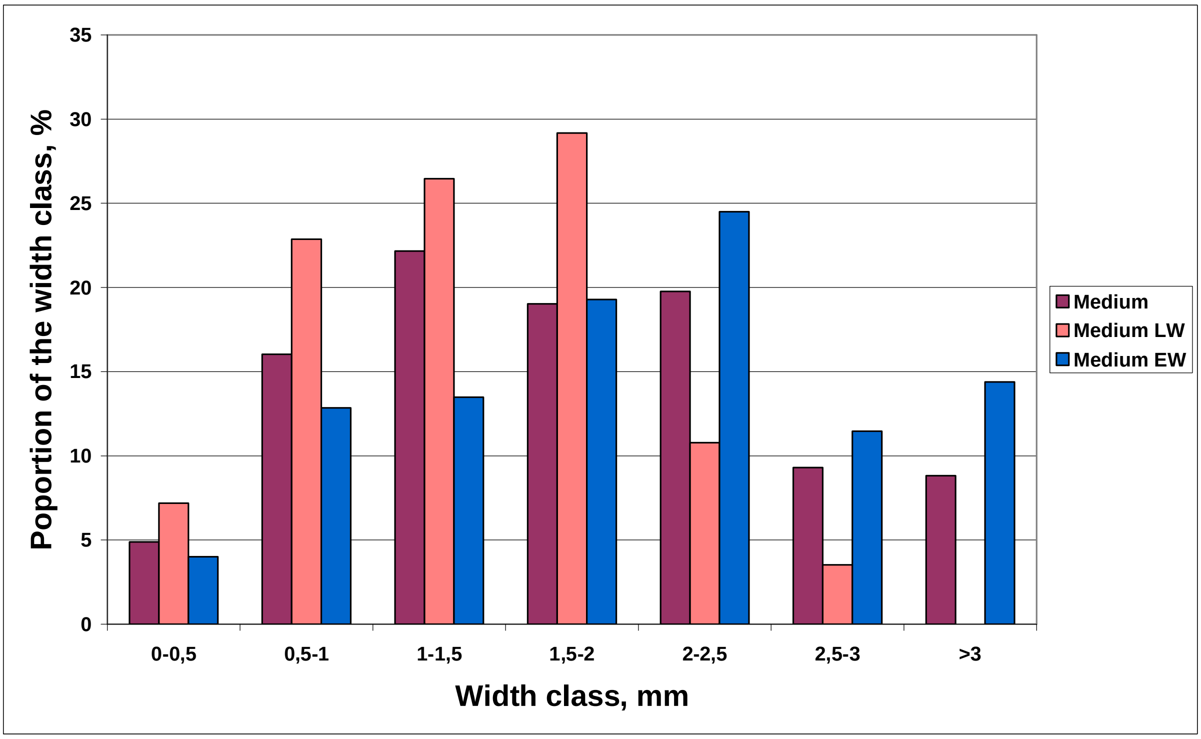

Figure 17. Width of fractionated medium grown pin chips.

Preliminary studies were done in a beaker, Figure 18. Medium density had a clear effect on sinking. Based on the preliminary studies the conditions of dynamic trials were chosen. The final conditions were chosen from the pre-trials with dynamic equipment. The trial conditions and main fractionation results are presented in the Table 1.

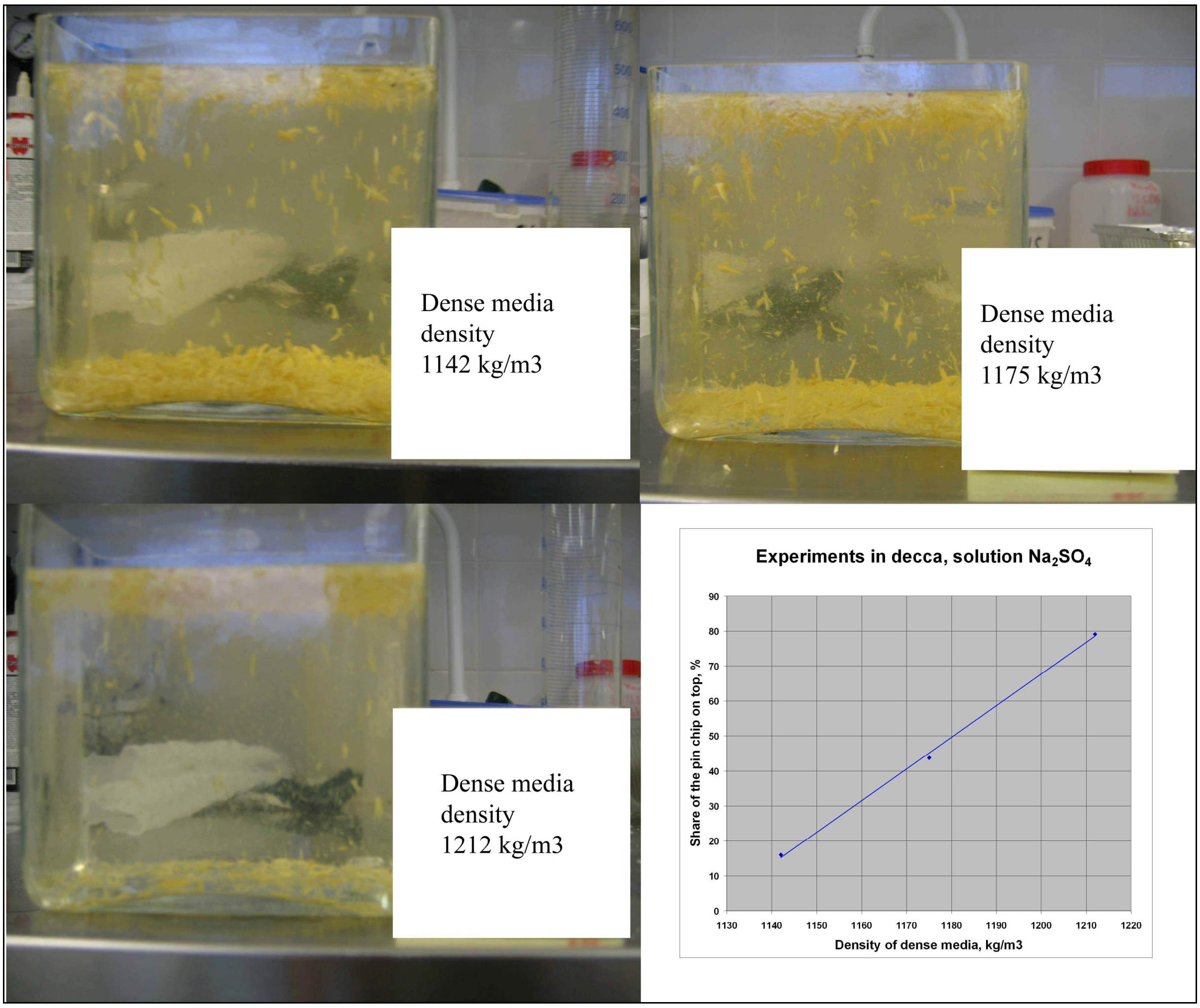

Figure 18. Experiments were done in static beaker by Na_2SO_4 solution. The amount of solution was 1.5 litres and pin chips 20 g dry.

Table 1. Fractionation conditions and main results.

Experiment	Material	Valve position	Density of NA_2SO_4 solution	Cyclone angle	Velosity of Dense media	Moisture content of feed pin chips	Share of EW fraction	Capasity
nro		°	kg/m3	o	litre/s	%	% (DS)	kg (DS)/h
4	P35 + P72 medium	47	1190	20	2,68	69,3	88	7,5
5	P35 + P72 medium	47	1160	20	2,68	71,0	75	8,2
6	P35 + P72 medium	47	1113	20	2,68	71,0	47	7,8
13	P35 + P72 medium	47	1074	20	2,68	71,0	17	6,9
7	P126 + P235 fast	47	1115	20	2,67	74,8	54	6,8
8	P126 + P235 fast	47	1075	20	2,68	74,8	22	7,8
9	P126 + P235 fast	47	1147	20	2,67	74,8	74	9,2
10	P21 + P129 slow	47	1157	20	2,67	73,2	81	8,0
11	P21 + P129 slow	47	1111	20	2,68	73,2	50	9,2
12	P21 + P129 slow	47	1072	20	2,67	73,2	18	7,7
14	P35 + P72 medium	47	1075	20	2,67	71,0	19	7,1
15	P35 + P72 medium	47	1158	20	2,67	71,0	76	7,4
16	P21 + P129 slow	49	1160	20	2,68	73,2	68	7,3
17	P126 + P235 fast	49	1074	20	2,68	74,8	16	7,2
KCL 1	P35 + P72 medium	49	1076	20	2,67	60,0	13	7,9
KCL 2	P35 + P72 medium	49	1166	20	2,67	60,0	62	8,3

Experiment	Basic density			Fibre length			Fibre width			Coarseness		
	Feed	Eearly wood	Latewood	Feed	Early wood	Latewood	Feed	Early wood	Latewood	Feed	Early wood	Latewood
nro	kg/m3	kg/m3	kg/m3	mm	mm	mm	µm	µm	µm	µg/m	µg/m	µg/m
4	369,0			1,85			34,8					
5	369,0	367,7	471,9	1,85	1,83	1,77	34,8	35,1	33,5	156	152	171
6	369,0	344,4	456,4	1,85	1,85	1,83	34,8	35,5	34,3	156	148	168
13	369,0	317,5	394,5	1,85	1,78	1,86	34,8	35,3	34,6	156	137	161
7	356,0	330,4	421,8	1,72	1,71	1,69	33,8	33,9	32,6	143	139	147
8	356,0	314,9	386,1	1,72	1,66	1,69	33,8	34,4	33,3	143	138	142
9	356,0	353,1	462,1	1,72	1,69	1,72	33,8	33,8	32,2	143	144	158
10	389,0	372,0	467,6	1,81	1,90	1,70	36,2	36,4	34,3	158	156	173
11	389,0	344,2	437,0	1,81	1,83	1,81	36,2	36,6	35,4	158	157	173
12	389,0	313,9	395,6	1,81	1,70	1,79	36,2	36,2	35,5	158	148	164
14	369,0	320,0	418,8	1,85	1,78	1,87	34,8	34,7	34,0	156	129	143
15	369,0	382,2	476,9	1,85	1,88	1,80	34,8	34,6	33,6	156	150	159
16	389,0	364,4	426,2	1,81	1,81	1,75	36,2	35,5	34,9	158	154	167
17	356,0	311,0	371,6	1,72	1,59	1,64	33,8	34,8	33,3	143	124	143
KCL 1	369,0	320,9	403,5	1,85	1,71	1,87	34,8	34,9	34,4	156	138	163
KCL 2	369,0	371,9	441,9	1,85	1,74	1,70	34,8	34,7	34,0	156	155	170

Basic density of fractions and original pin chips are presented in Figure 19 and 20. The largest difference in basic density was 165 kg/m^3. That is between early wood fraction from fast grown wood and latewood fraction from slowly grown wood. In original logs, the greatest basic density difference was between fast and slowly grown logs, and that was 33 kg/m^3.

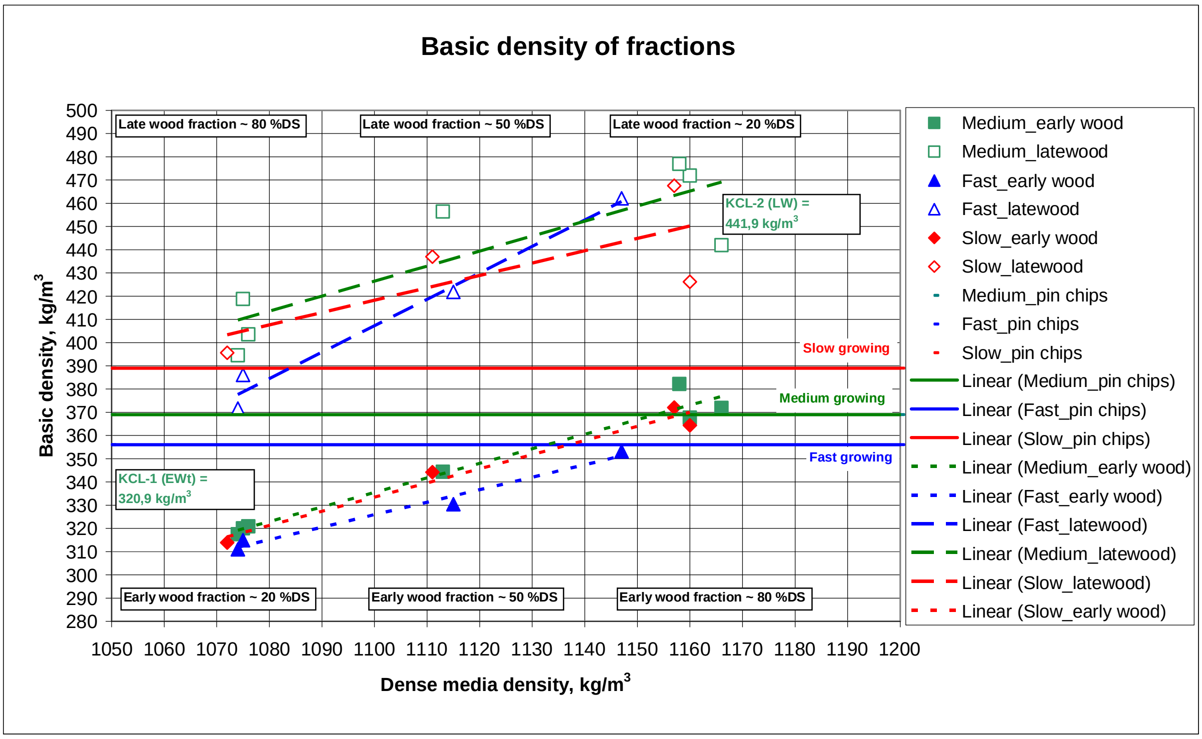

Figure 19. Basic densities of fractions versus dense media density.

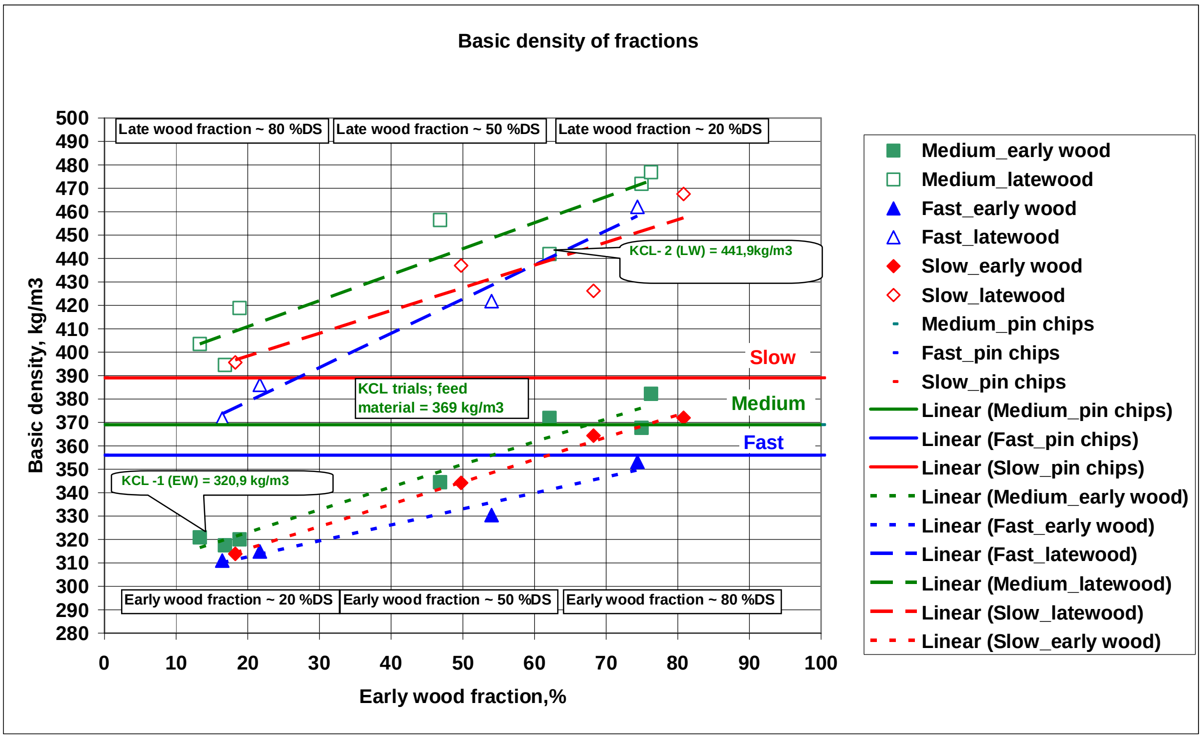

Figure 20. Basic densities of fractions versus separated early wood fraction.

Coarseness values of the fractions and original pin chips are presented in the Figure 21. The difference of coarseness value in one stage fraction varies between 4-25 µg/m. The largest difference in coarseness 49 µg/m was noticed between early wood fraction from fast grown wood and latewood fraction from slowly grown wood. In original logs, the largest coarseness difference was between fast and slowly grown logs, and that was 15 µg/m. The results are rather logical, because in the most cases one of the fractions have lower coarseness value than the original pin chips and while the other fraction has higher coarseness value.

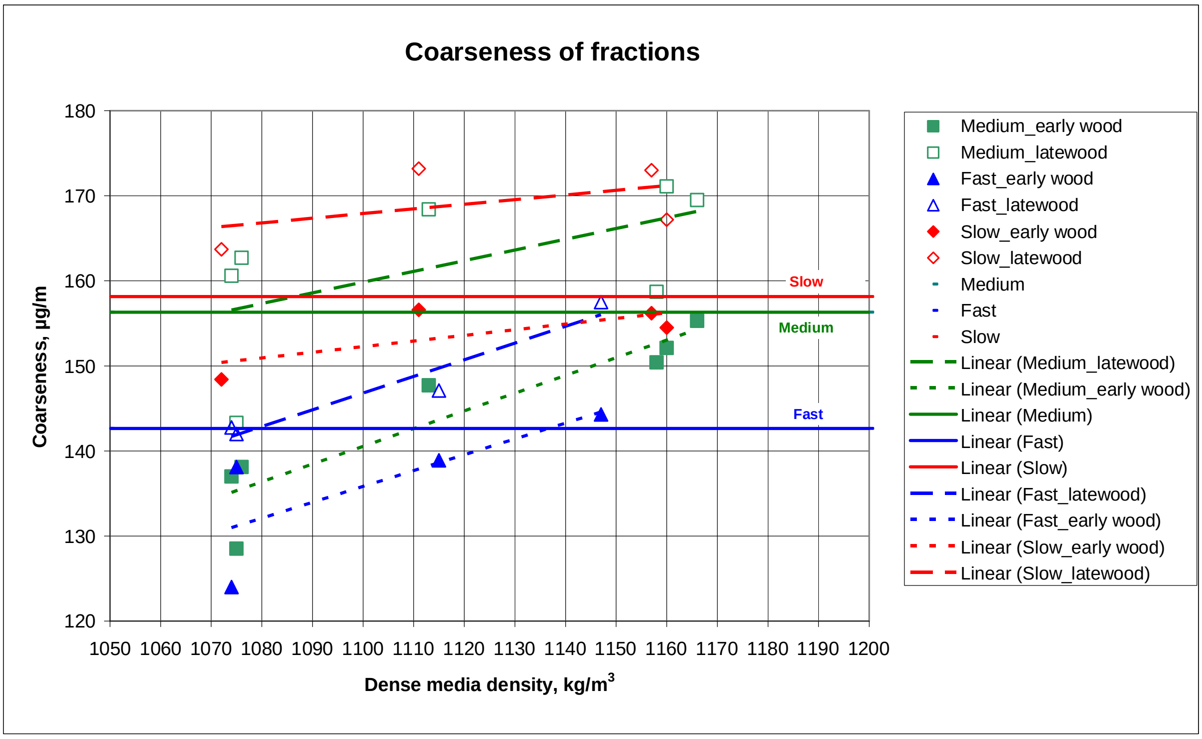

Figure 21. Coarseness of fractions versus dense media density.

The fibre length results of the fractionation trials are presented in the Figure 22. The results are not logical in the cases when the both fraction have shorter fibre length than the original pin chips. However, differences are small and inside the sampling and analysis limits.

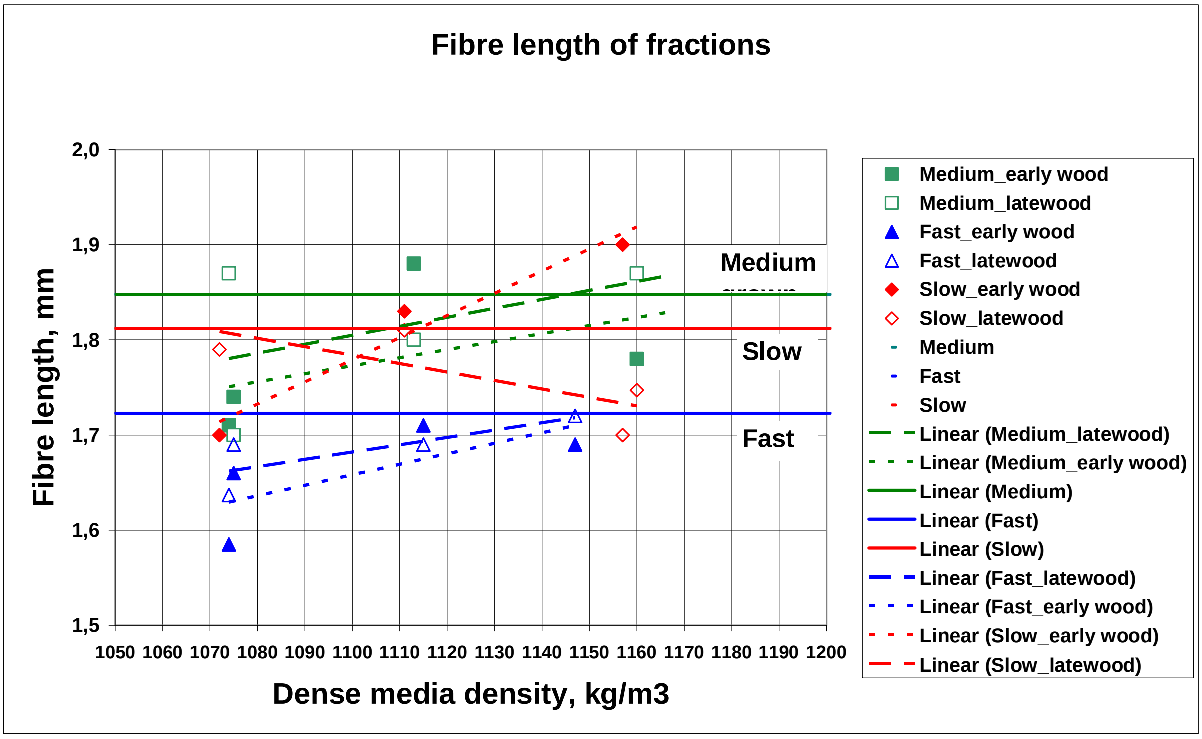

Figure 22. Fibre length in fractionation trials.

The fibre width results of the fractionation trials are presented in the Figure 23.

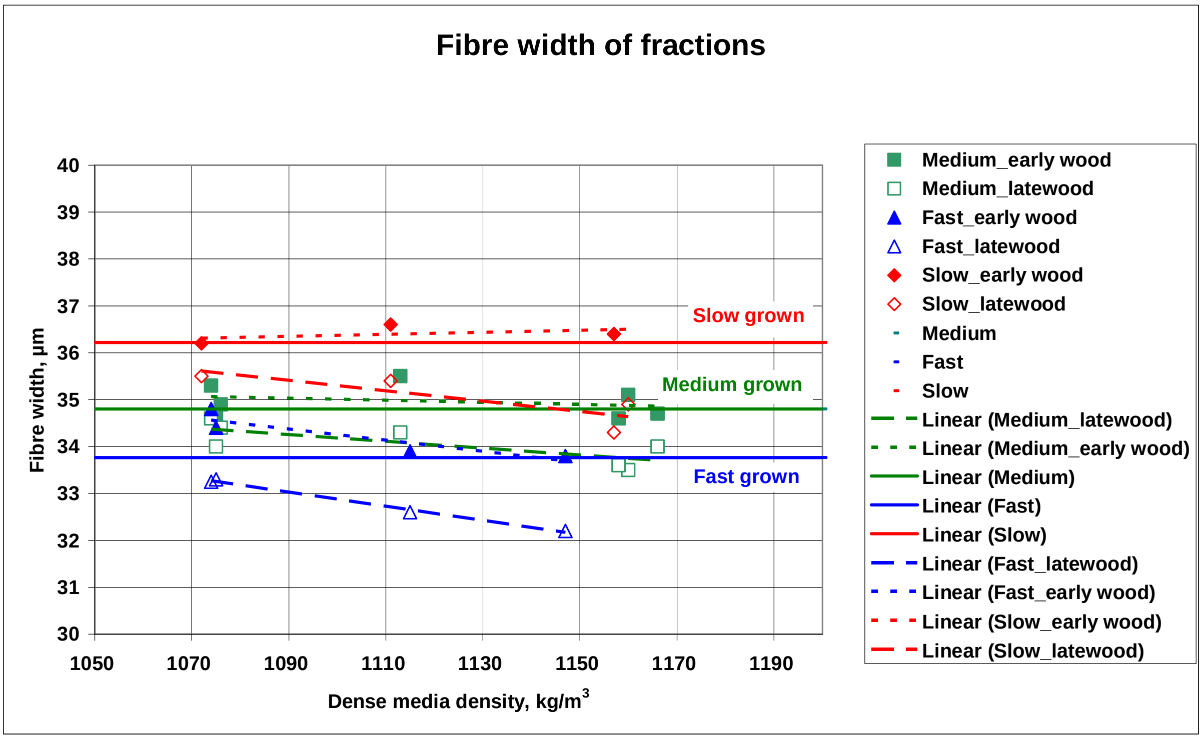

Figure 23. Fibre width in fractionation trials.

6.3 Fibre and paper properties and SEC in mechanical pulping

Specific energy consumption (SEC) of different growth rate pine samples in TMP-refining is presented in the Figure 24. Refining of fast grown pine consumes more energy than slowly grown.

Specific energy consumption of medium grown pine and its early and latewood fractions are presented in Figure 25. The differences are very small, but it seems that refining of early wood fraction consumes more energy than latewood fraction. The result is analogous with the result of refining different growth rate pin chips.

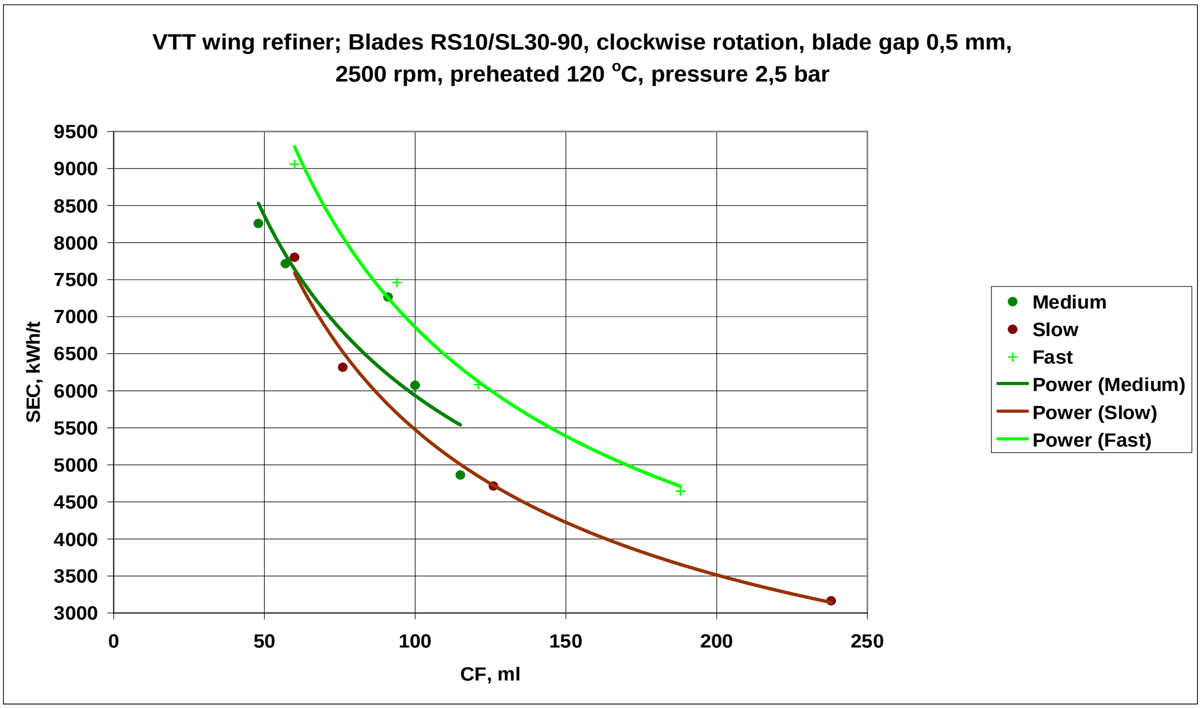

Figure 24. SEC in refining different growth rate pine pin chips.

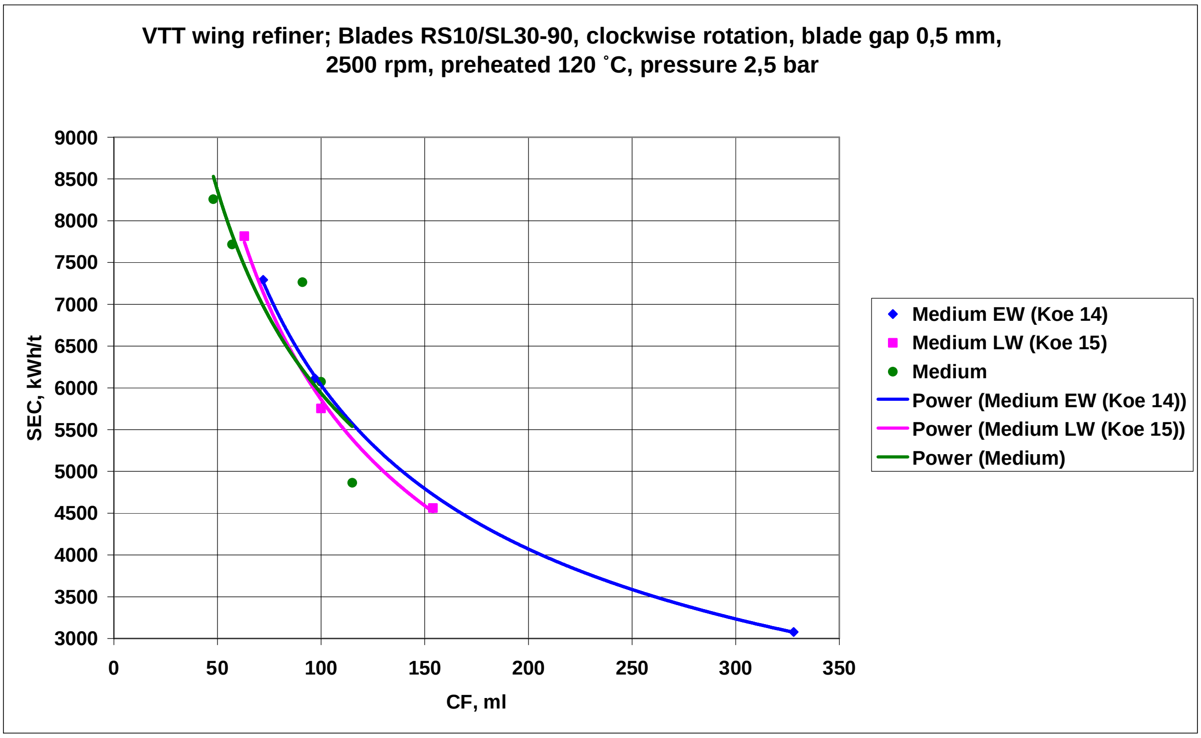

Figure 25. SEC in refining medium grown pine pin chips.

Very large specific energy consumption difference, 47 %, was achieved when comparing the refining behaviour of slowly grown latewood with that of fast grown early wood, Figure 26.

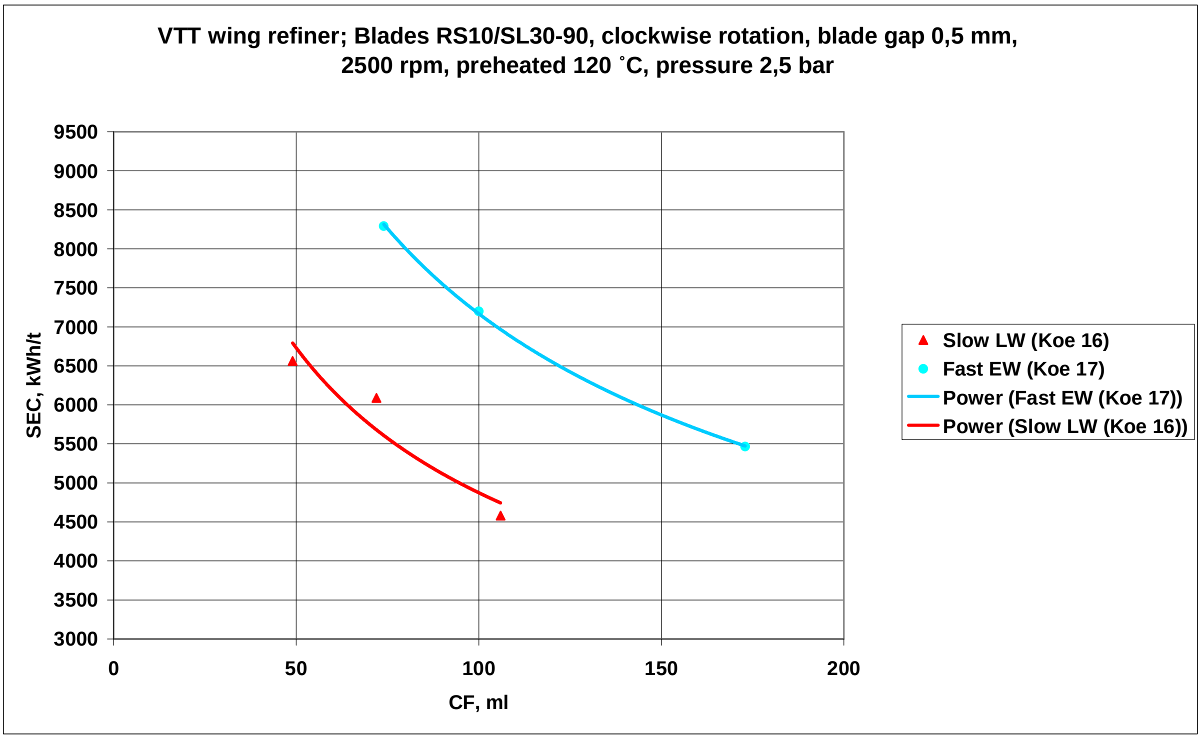

Figure 26. Maximal difference in SEC.

Growth rate and fractionation had only a very small effect on fibre length of screened pulp, Figure 27.

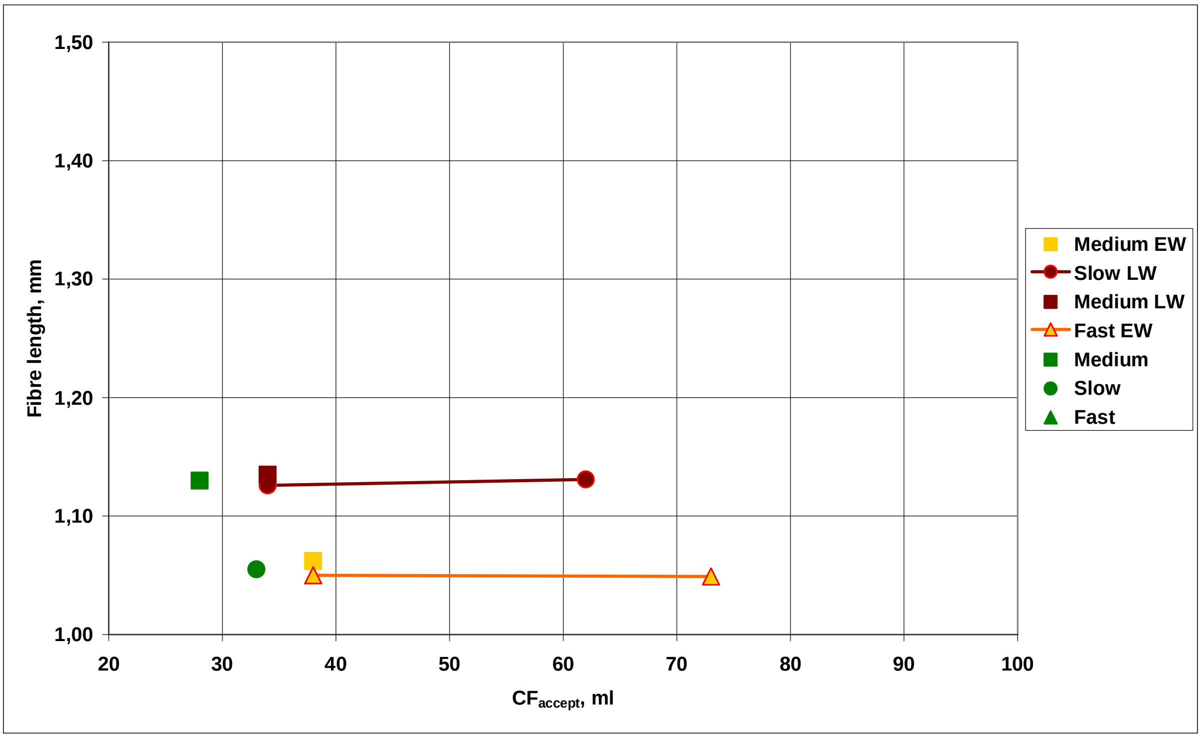

Figure 27. Fibre lengths of accepted pulps.

Pitäisikö tässä välissä kertoa, että jauhetuista massoista tehtiin laboratorioarkit (60 gsm? , kiertovesi) ja määritettiin paperitekniset (viittaus standardiin mitä käytetty), olisi loogista, koska nämä on mainittu myös sellunvalmistusosiossa.

Refined early wood fraction and fast grown pine have higher laboratory sheet density than the sheets from slowly grown pine or early wood fraction, Figure 28.

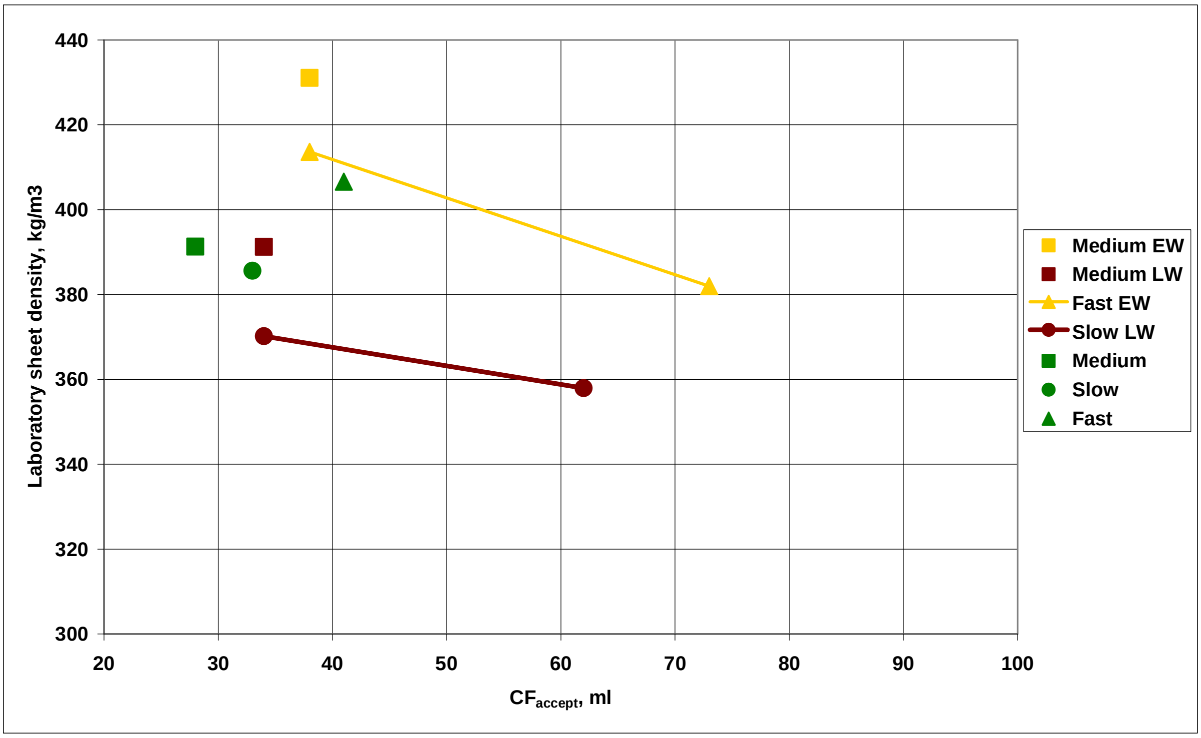

Figure 28. Density of the laboratory sheets.

Early wood fraction and fast grown wood had higher bendability than medium or slowly grown wood and latewood fraction, Figure 29.

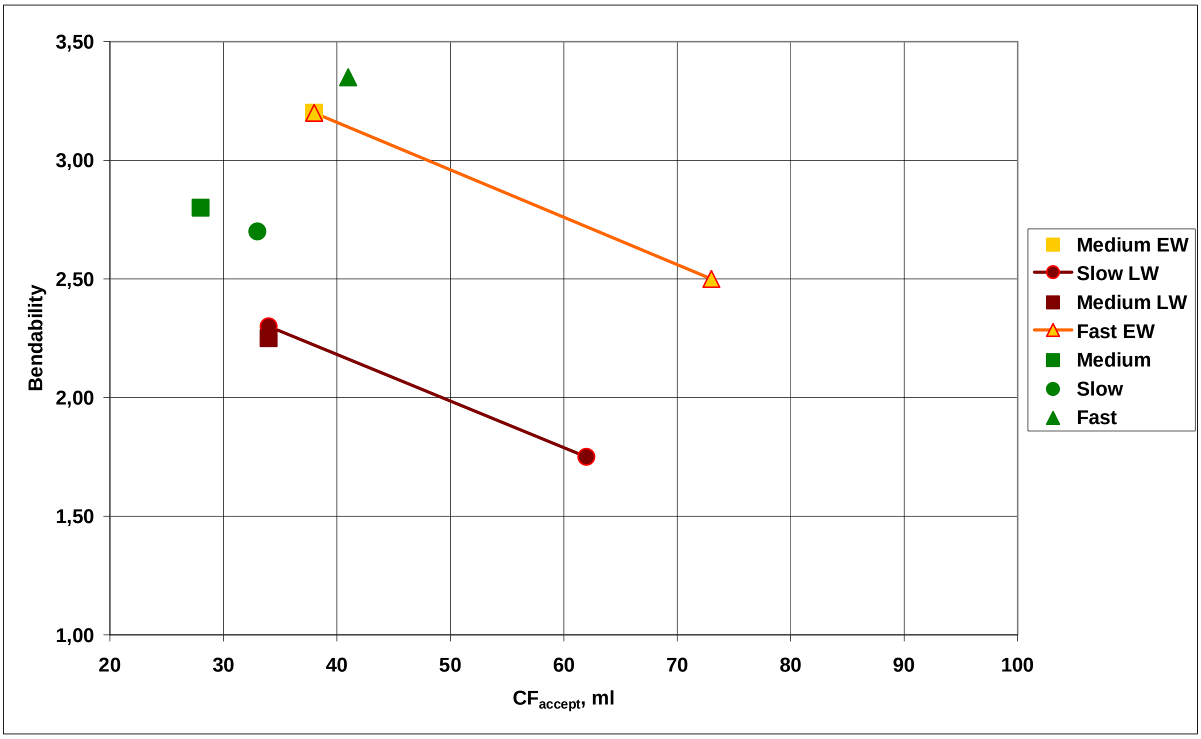

Figure 29. Bendability.

Pulp from early wood fraction had lower roughness at the same freeness level than pulps from un-fractionated or latewood fractions, Figure 30.

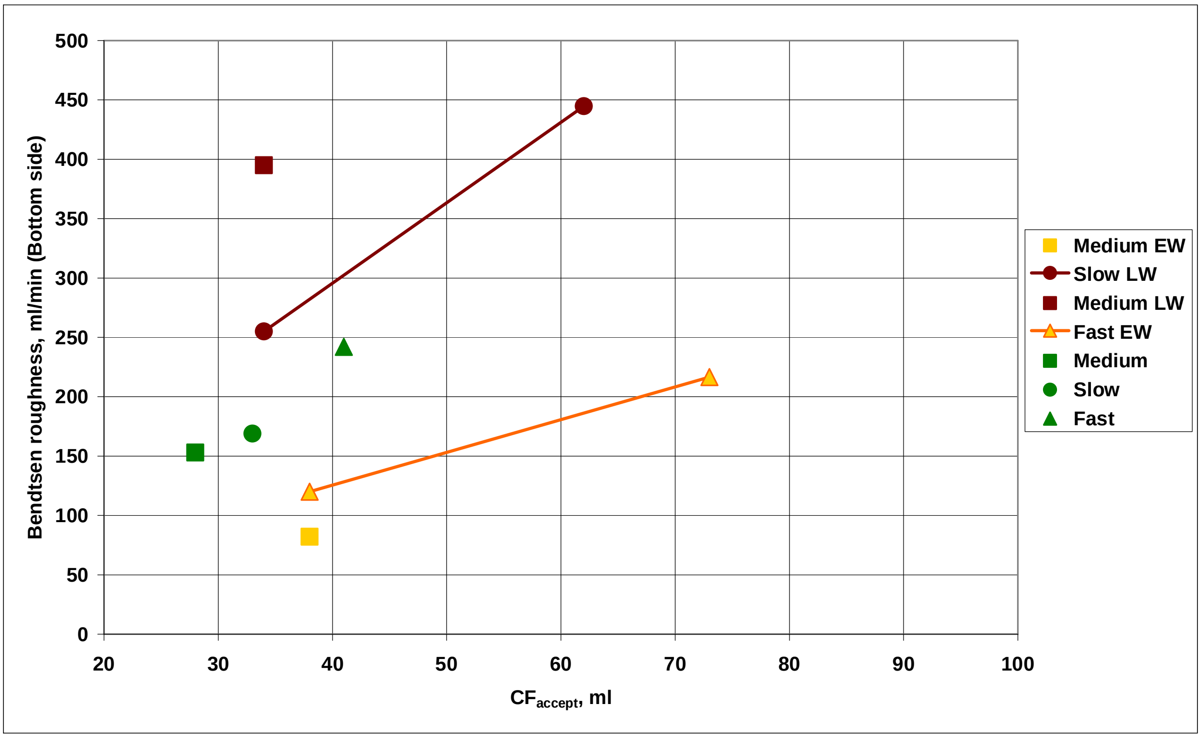

Figure 30. *Bendtsen roughness.*

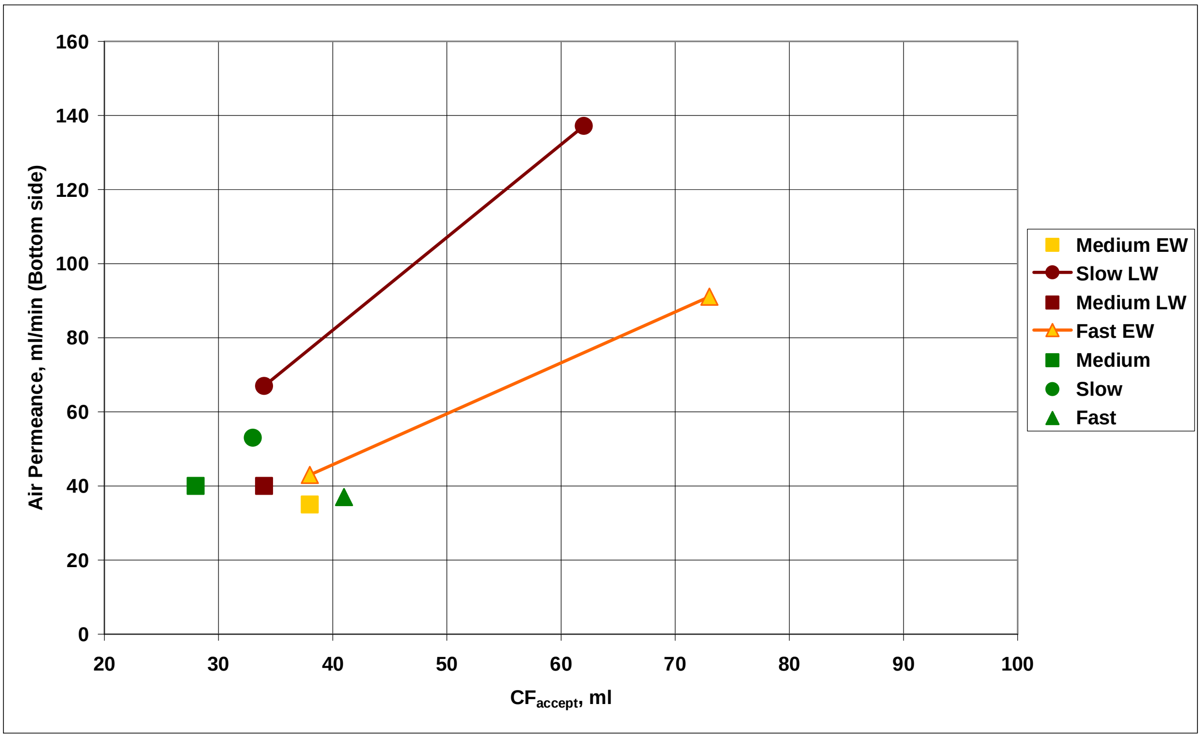

Figure 31. *Air permeability.*

Pulps from early wood fraction had higher tensile index at the same freeness level than pulps from un-fractionated or latewood fractions, Figure 32. The result is consistent with the literature, see Figure 7.

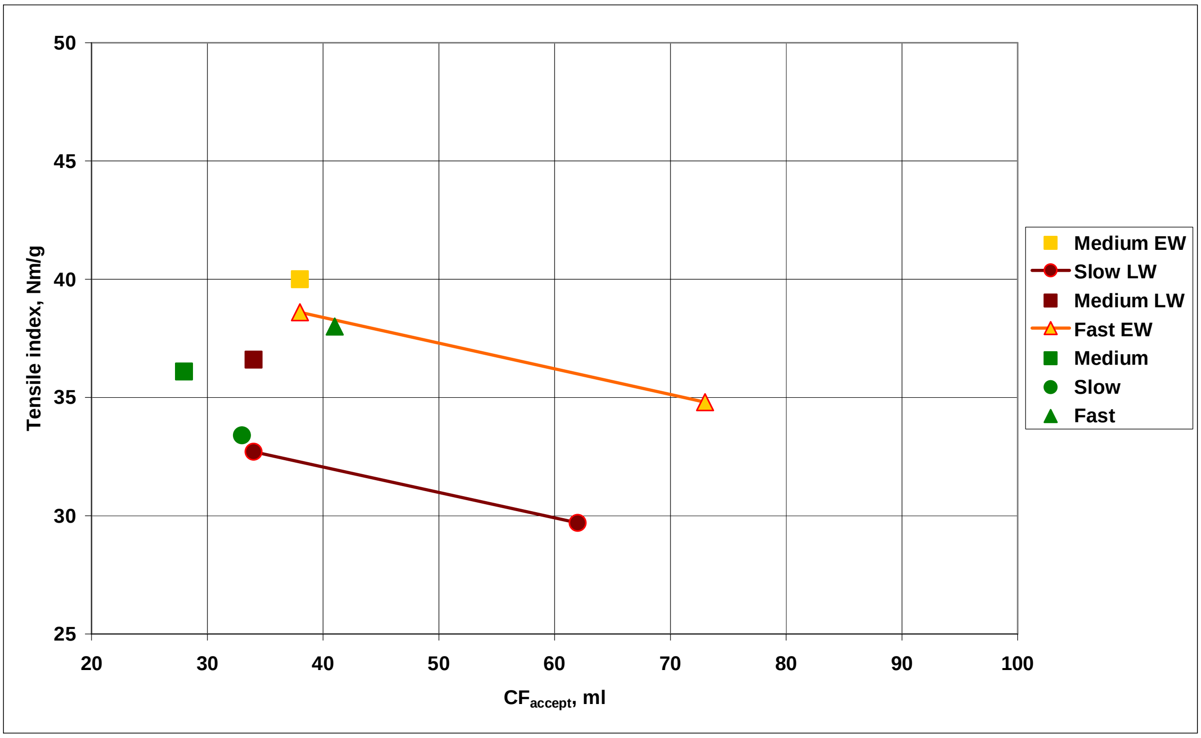

Figure 32. Tensile index.

Lower basic density results low roughness, Figure 33.

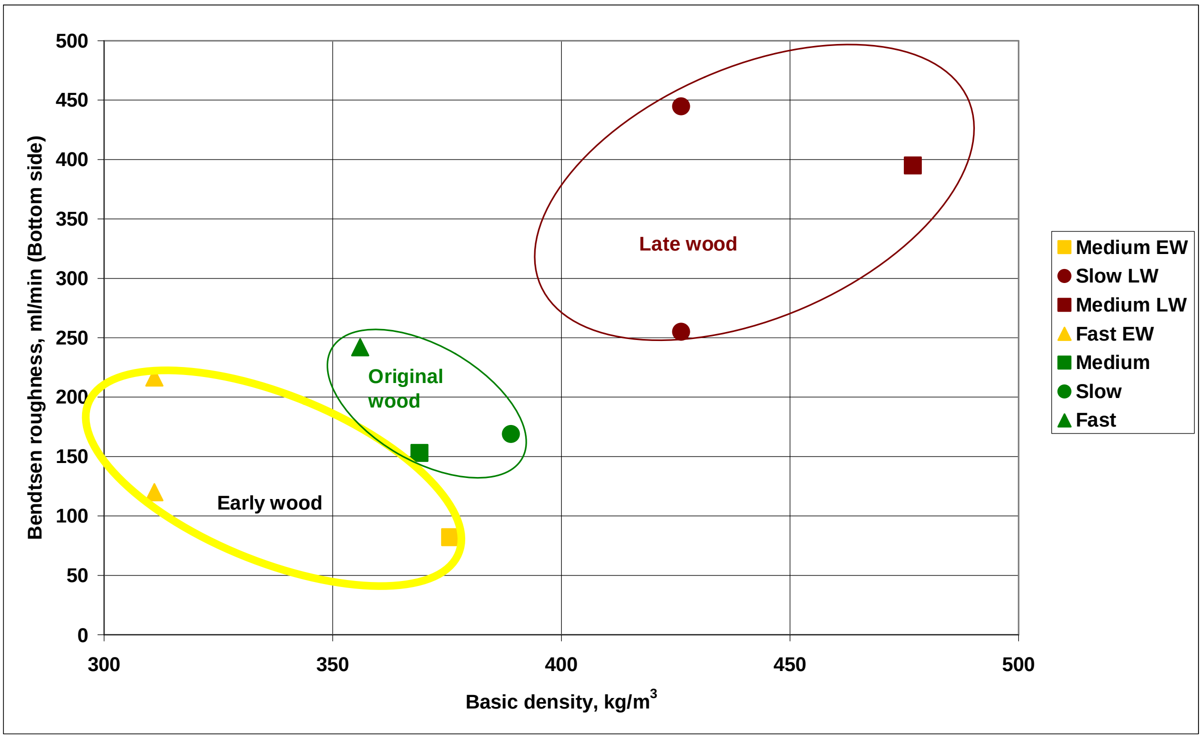

Figure 33. Bendtsen roughness vs. basic density.

Low Bendtsen roughness requires a lot of refining energy, Figure 34.

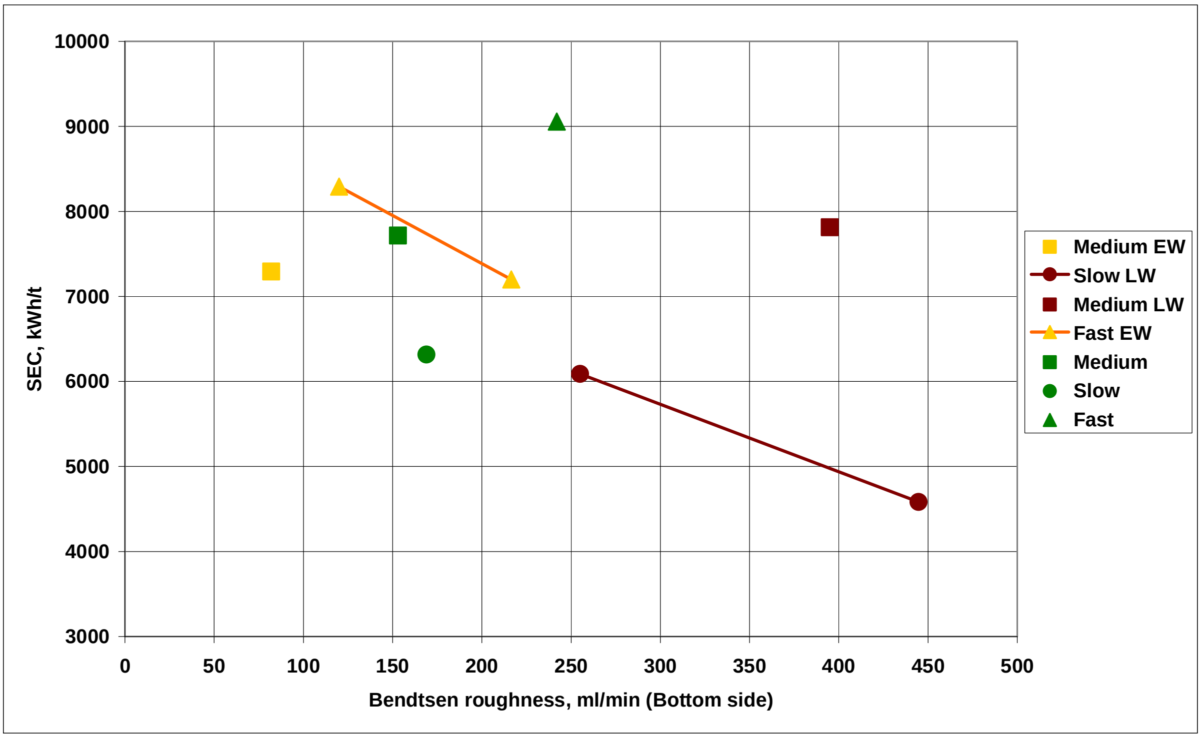

Figure 34. *SEC vs. Bendtsen roughness.*

6.4 Cooking experiments

The aim of the cooking experiments was to examine how the cooking of early wood and late-wood rich pine fraction differs from each other.

The raw materials for the cooking trials were delivered to KCL by VTT. The samples were more like pin chips or sawdust than normal chips. The three samples and their basic densities were:

reference (ref) 366 kg/m^3
early wood rich fraction (ew) 321 kg/m^3
latewood rich fraction (lw) 442 kg/m^3

First, the H-factor series were done for all the three samples. Later, the accuracy of the yield results was checked by air drying the wood samples to have more even sample for the dry solids content determination and weighing, and thus more reliable results. In these tests the target kappa numbers were 25 and 30. The air dried samples were kept in water in room temperature for half an hour before cooking.

After the cookings, the pulps were disintegrated in a British disintegrator, washed with de-ionized water, screened with a TAP 03 laboratory screen (0.15 mm slot), centrifuged and homogenized. Determinations were made for total yield, screenings, kappa number (ISO 302) and brightness (ISO 2470:99). The black liquors were analyzed for pH and residual alkali (SCAN-N 33:94). From three samples (kappa 25) viscosity (SCAN-CM 15:99), fibre length (Kajaani FS300), density (ISO 5270:1998), tensile (ISO 5270:1998) and tear (ISO 5270:1998) were determined.

6.4.1 Results

The cooking report is shown in the Table 2 and the pulp properties in the Table 3.

Table 2. Cooking report.

BASIC DATA				CHIP DATA		CHEMICAL CHARGE			TEMPERATURE		PULP					BLACK LIQUOR	
Order No.	Cooking No.	Date	Cooking method	Chip mark	Dry matter content %	EA mol/kg	Sulfidity %	L/W %	Cooking temp. °C	H-factor	Yield %	Shives %	Total yield %	Kappa number	Brightness %	pH	Residual alkali gNaOH/l
2005-302	1744M	4.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	800	45.2	0.05	45.2	35.7	33.1	13.4	15.4
2005-302	1750M	9.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	950	44.1	0.03	44.2	28.1	34.8	13.4	15.2
2005-302	1753M	9.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	1050	43.6	0.05	43.7	24.7	35.6	13.4	13.7
2005-302	1747M	4.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	1200	43.3	0.02	43.3	23.4	36.6	13.4	13.1
2005-302	1746M	4.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	800	44.1	0.02	44.2	38.8	36.8	13.4	16.5
2005-302	1752M	9.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	950	43.5	0.07	43.5	33.3	38.0	13.4	16.6
2005-302	1755M	9.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	1050	42.9	0.09	43.0	27.8	39.7	13.4	15.6
2005-302	1749M	4.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	1200	42.4	0.03	42.4	24.7	41.0	13.4	13.9
2005-302	1745M	4.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	800	42.8	0.04	42.9	32.6	37.8	13.4	16.0
2005-302	1751M	9.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	950	42.0	0.06	42.1	26.8	39.8	13.4	15.6
2005-302	1754M	9.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	1050	41.7	0.10	41.8	24.5	40.7	13.4	15.0
2005-302	1748M	4.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	1200	41.0	0.01	41.1	20.6	42.6	13.4	13.9
2005-302	1766M	1.4.2009	Purukeitto	ref dry	91.8	6	35	4.5	180	900	44.4	0.04	44.5	28.8	32.8	13.3	14.4
2005-302	1769M	1.4.2009	Purukeitto	ref dry	91.8	6	35	4.5	180	1050	43.8	0.06	43.8	25.7	34.0	13.2	13.3
2005-302	1768M	1.4.2009	Purukeitto	ew dry	90.1	6	35	4.5	180	1000	42.6	0.04	42.6	27.1	39.1	13.3	15.2
2005-302	1771M	1.4.2009	Purukeitto	ew dry	90.1	6	35	4.5	180	1200	42.0	0.04	42.0	22	41.5	13.3	13.8
2005-302	1767M	1.4.2009	Purukeitto	lw dry	91.9	6	35	4.5	180	850	42.8	0.06	42.9	29	38.7	13.3	15.8
2005-302	1770M	1.4.2009	Purukeitto	lw dry	91.9	6	35	4.5	180	1050	41.8	0.04	41.8	24.3	40.7	13.3	14.0

Table 3. Pulp properties.

Sample		Number of tests	Ew 1749 m	Ref 1753 m	Lw 1754 m
Wet disintegration of chemical pulp	ISO 5263-1:2004				
Fibre distribution, FS-300	□				
- Arithmetic av. fibre length, mm			0.70	0.79	0.72
- Length weighted av. fibre length, mm			1.53	1.66	1.54
- Weight weighted av. fibre length, mm			2.13	2.26	2.19
- Length < 0,2 mm, %			5.36	4.17	4.46
- Fiber curl, %			7.5	7.7	7.1
- Kink index, 1/m			350	375	349
- Fiber width, µm			24.8	25.1	24.8
Grammage, g/m² *)	ISO 5270:1998		66.1	66.3	66.4
Bulking thickness, µm *)	ISO 5270:1998, ISO 534:1988	5	87.4	100	106
Standard deviation, µm			1.7	2	3
Apparent bulk-density, kg/m³ *)	ISO 5270:1998, ISO 534:1988	5	756	661	629
Standard deviation, kg/m³			14	13	15
Bulk, cm³/g *)	ISO 534:1988	5	1.32	1.51	1.59
Standard deviation, cm³/g			0.03	0.03	0.04
Tensile strength, kN/m *)	ISO 5270:1998, EN ISO 1924-2:1994	10	5.84	4.48	4.10
Standard deviation, kN/m			0.25	0.17	0.13
Tensile index, Nm/g *)	ISO 5270:1998, EN ISO 1924-2:1994	10	88.4	67.5	61.7
Standard deviation, Nm/g			3.8	2.6	1.9
Stretch, % *)	ISO 5270:1998, EN ISO 1924-2:1994	10	2.6	2.3	2.2
Standard deviation, %			0.2	0.2	0.1
Tensile energy absorption, J/m² *)	EN ISO 1924-2:1994	10	103	70.0	62.9
Standard deviation, J/m²			12	9.1	5.0
TEA index, J/g *)	EN ISO 1924-2:1994	10	1.57	1.06	0.948
Standard deviation, J/g			0.18	0.14	0.075
Tensile stiffness, kN/m *)	EN ISO 1924-2:1994	10	606	511	483
Standard deviation, kN/m			10	11	14
Tensile stiffness index, kNm/g *)	EN ISO 1924-2:1994	10	9.17	7.70	7.27
Standard deviation, kNm/g			0.16	0.17	0.21
Modulus of elasticity, N/mm² *)	EN ISO 1924-2:1994	10	6934	5095	4571
Standard deviation, N/mm²			120	111	129
Tearing strength, mN *)	ISO 5270:1998, ISO 1974:1990	5	583	833	881
Standard deviation, mN			14	24	40
Tear index, mNm²/g *)	ISO 5270:1998, ISO 1974:1990	5	8.82	12.6	13.3
Standard deviation, mNm²/g			0.21	0.4	0.6

Arrival date:25.5.2009
Date of tests: 26.5.2009/ask
Test conditions: 50% RH, 23°C
Approval: 26.5.2009 ELK

Compared at a constant H-factor, the lw-fraction was cooked to lower kappa number than ew-fraction (Fig. 35). When air-dried raw materials were use, the difference was much smaller. The yield of lw-pulps was lower than that of ew-pulps (Fig. 36 left). Both fractions got smaller yield than the reference indicating that something was lost or some reactions have taken place during the fractionation and washing processes. This has also affected the higher brightness of the fraction-pulps (Fig. 36 right).

The viscosities of the pulps at kappa level 25 were 920 (ref), 890 (ew) and 900 (lw) indicating that the yield loss is not because of excess dissolving of hemicelluloses (the viscosity of the fraction-pulps is not higher than that of the reference).

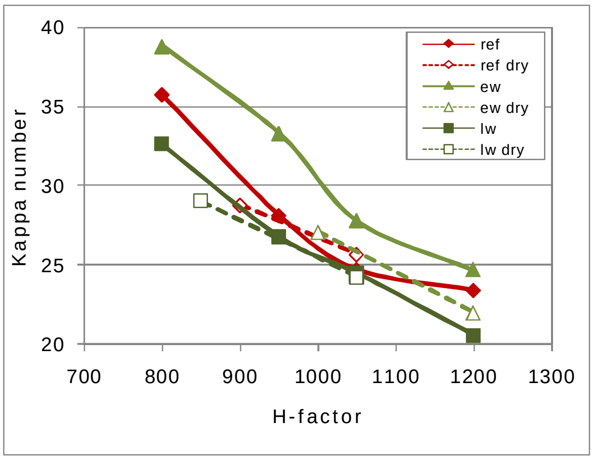

Figure 35. Kappa number as a function of H-factor.

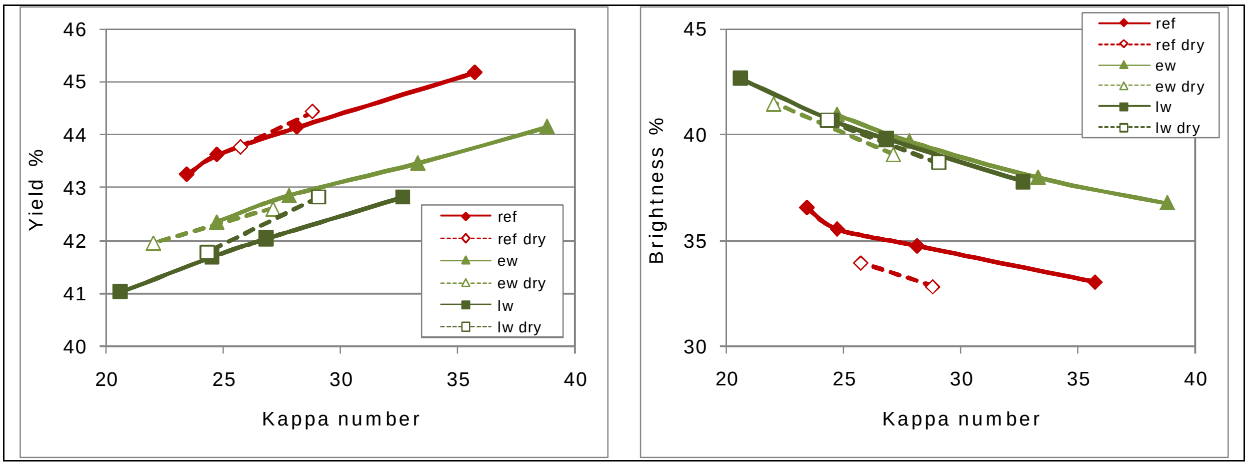

Figure 36. Total yield and pulp brightness as a function of kappa number.

Both fraction-pulps had 0.1 mm lower fibre length than the reference, Table 4. In general, severe fibre cutting has taken place already during the preparation of the pin chips (initial fibre length ca. 2.5 mm). The density of the laboratory sheets made of ew-pulp had much higher density, higher tensile and lower tear index than the lw-pulp. In general, the lw-pulp properties were closer to the reference pulp, but the ew-pulp was clearly different.

Table 4. Fiber length and sheet properties of the cooked pulps.

Sample	ref	ew	lw
Fiber length, lw, FS300, mm	1.66	1.53	1.54
Apparent bulk-density, kg/m³	661	756	629
Tensile index, Nm/g	67.5	88.4	61.7
Stretch, %	2.3	2.6	2.2
Tear index, mNm²/g	12.6	8.82	13.3

7 Validation of results

The pin chips production process is reliable. The production capacity (about 500 kg DS/h) was in the level which had steady flow.

Fractionation process is stable. The STDEV of dense media flow has measured in earlier studies to be 0.07 l/s, STDEV of dense media density 5.4 kg/m3 and STDEV of early wood fraction proportion 3.1 %-units when fractionated 30 % EW/70 % LW. The difference of basic density in parallel analysis has been 2.2-7.1 kg/m^3. Analysis error (tn_{95}) has been 5 kg/m^3. We conclude that the fractionation process is very stable. The measured difference in dense media fractionation (60-100 kg/m^3) is significant.

The pulps were screened by FS-03 (# 0.13 mm slotted screens, profile 1.1 mm). The analysis results are expected to be reliable, even though the results do not represent the properties of whole pulp. The number of laboratory sheets analysed in each point is 5-7 and standard is 10. Breaking index is not measured because of too small number of sheet. Other paper properties are considered to be reliable.

The wood sample in each growth rate includes only pulp wood part of two stems. That is rather small. Besides, the slowly grown stems had large difference in basic density between the stems. The result is not statistically reliable, but only suggestive.

Refining trials are made in laboratory scale by VTT wing refiner. The refining conditions were not optimized for each fraction, but refined in same conditions. The results should be verified in larger scale.

The cooking trials were made in laboratory scale and only with two fractionation samples. The fractions had not the maximum difference in basic density and the samples were not the same, which had the maximum difference in mechanical refining. The cooking trials are only introductory.

8 Summary

Pine logs with three different growth rates were delivered for fractionation and pulping studies from Metla´s experimental plot. The logs were debarked and chipped at VTT and their average basic densities were determined. The maximum density and coarseness difference of the samples were 33 kg/ m^3 and respectively 15 µg/m in the sample logs. Some sample logs were also analysed at STFI Packforsk with so called Silviscan method.

The size of chips was reduced to <2 mm in thickness in order to separate the early wood from latewood with a method developed at VTT. The resulting pin chips were then steamed and impregnated with water (to remove air and to fill lumen and pores with water). Fractionation of chips was done using so called dense media fractionation method. Density of fractionating medium was adjusted according to the desired basic density of the fractions. Concentrated sodium sulphate solution was used as fractionating medium. Continuously operated prototype fractionation equipment was used for fractionation trials.

According to the results dense media fractionation can be used to increase basic density and coarseness difference of pin chips. The maximum basic density difference between 20 % of lightest and 20 % heaviest fraction was 150 kg/m^3 that is respectively in industrial wood 40 kg/m^3. The coarseness difference in the respective fractions was 50 µg/m.

The mechanical pulping trials revealed that density is very important raw material parameter in terms of energy consumption and pulp quality. The greatest energy consumption difference

of the fractions was 47 %. Fractionation increased also the surface roughness and density difference of paper samples.

Also standard cooking trials of the fractions were done, but only for medium growth rate fractions. Yield and brightness differences between fractions were measured, but more studies should be done to conclude the differences. Optimised cooking conditions of fractions should reveal larger fibre level differences.

The cooking of latewood fraction to certain kappa number required shorter cooking time than cooking of ew-fraction. The pulp properties were close to the reference. Instead, the early wood pulp had clearly different pulp properties: higher density, higher tensile and lower tear.

These were the first cooking experiments with this kind of wood fractions. Definite conclusions cannot be drawn based on these few tests. In the future, more experiments should be done to ascertain the results. Reference raw material, which is treated similarly as the references, should be tested. In addition, it should be studied what happens during the fractionation and washing (loss of certain substances or particles, reactions, etc.). Comparison to cooking with normal chips should be done as well, although the optimal cooking conditions for normal chips and pin chips/sawdust are different.

Further, the bleachability and beatability of the pulps, and the effect on paper properties in blend sheets could be examined. Effect on surface properties of the paper is one issue of interest, including the effect on calendering.

Fractionation of Norway spruce has been studied earlier using a single-stage dense media fractionation concept. This study implies that dense media fractionation may offer several advantages to homogenize the pulping material, improve the efficient fibre production, broaden the properties of fibre supply and offer new product characteristics for fibre based products.

As the next step, larger scale fractionation trials with commercial equipment followed by pilot scale mechanical and chemical pulping are proposed. Fractionation should also be considered as a multi-stage process (Figure 37). Dense media fractionation may be used to

- homogenization of pulping raw material,
- reducing energy consumption and costs of fibre production,
- broadening the properties of fibre supply,
- delivering new fibre product characteristics.

Energy and chemical saving potential is proposed to be studied by mixing mechanical and chemical pulps at different freeness levels produced from different fractions. Early wood fraction should be refined to higher freeness level than latewood fraction and save energy in this way.

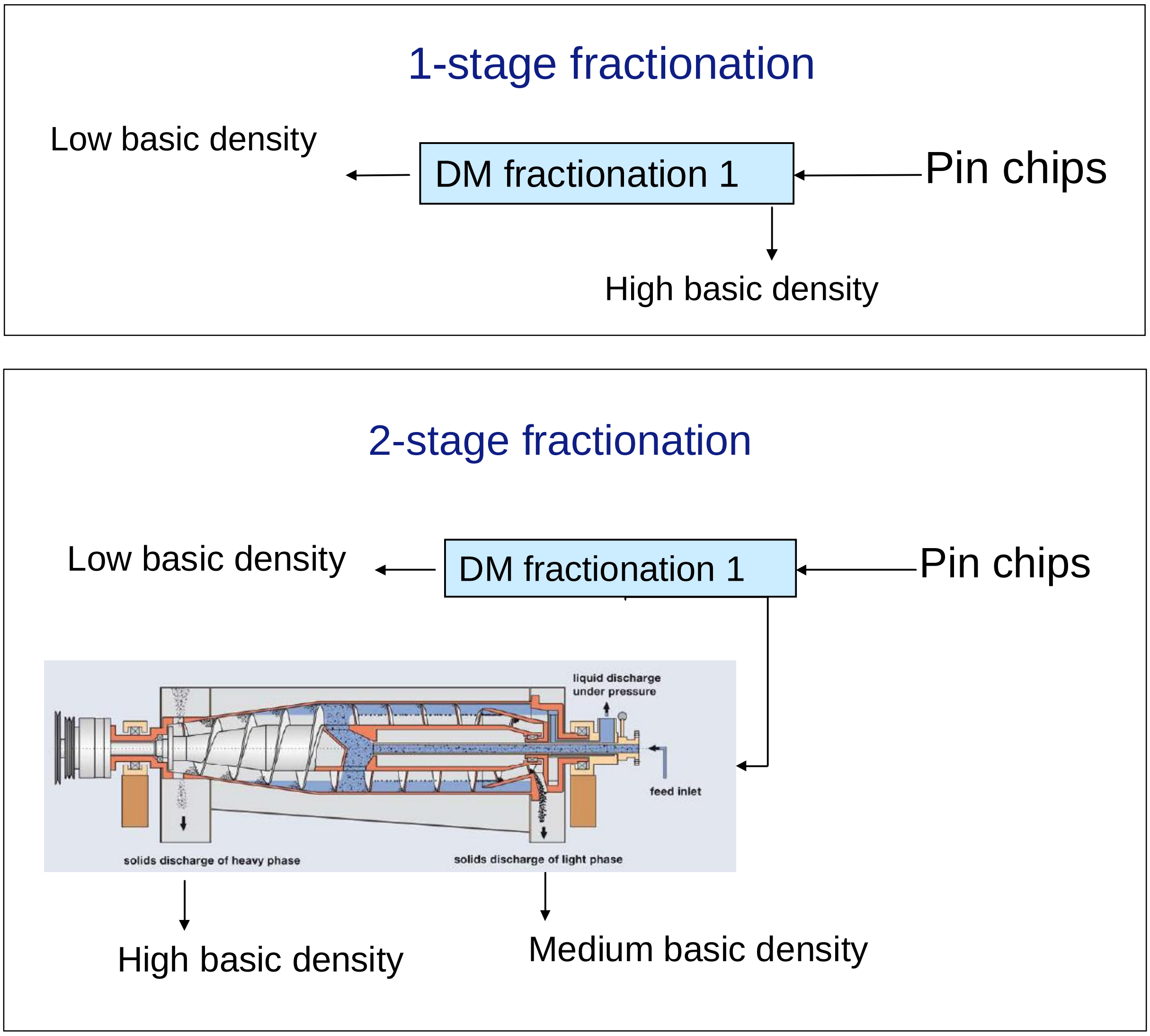

Figure 37. Principles and 1- or 2-stage fractionation process.

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Appendix 1

Characterisation of wood samples

The sample trees were harvested from two different experiments and from tree different experimental plots, Table 5. The trees 126 and 235 were fast grown, trees 35 and 72 medium grown and trees 21 and 129 slowly grown. The fast grown trees had thickest branches and less dead branches.

The properties of the samples are in Table 6. The bark content in the sample logs was 10 % (green weight-%). The moisture content of wood was 40 % and bark 37 %.

Table 5. Sample trees.

Experiment	Experimental plot	Growth rate	Tree number	Height of the tree	$D_{1,3}$	Branch diameter	Dead branches
				m	cm	mm	%
509	2	Fast	126	26,7	38,7	39	0
			235	24,9	34,7		
509	1	Medium	35	25,2	24,2	19,4	90
			72	23,2	23,2		
512	7	Slow	21	19,1	20	15,9	63
			129	17,9	20,4		

Table 6. Properties of the sample trees.

Number of the log	But end of the pulp wood log				Top end of the log				Length of the log, cm	Basic density of the log, kg/m^3
	Diameter under the bark, mm	Annual rings	Awerage annual growth, mm	Basic density of the sample disc, kg/m^3	Diameter under the bark, mm	Annual rings	Awerage annual growth, mm	Basic density of the sample disc, kg/m^3		
P72-1	147,5	27	2,73	368	126,5			377	245	372
P72-2	126,5	23	2,75	377	106,5			369	257	373
P72-3	106,5	18	2,96	369	89,5			367	242	368
P72-4	89,5	14	3,20	367	43,5	7	3,11	335	189	351
P35-1	142,5	24	2,97	399	117,5			404	257	402
P35-2	117,5	18	3,26	404	95,5			381	247	393
P35-3	95,5	16	2,98	381	54	8	3,38	368	228	375
Medium			3,04							376
P126-1	147	16	4,59	356	96,5			355	250	355
P126-2	96,5	12	4,02	355	54,5	5	5,45	353	243	354
P235-1	148,5	21	3,54	377	111,5			362	264	369
P235-2	111,5	17	3,28	362	59	10	2,95	364	254	363
Fast			3,97							360
P21-1	142,5	31	2,30	413	125			397	279	405
P21-2	125	25	2,50	397	94			391	271	394
P21-3	94	22	2,14	391	60,5	9	3,36	380	271	386
P129-1	147	30	2,45	370	127,5			361	228	365
P129-2	127,5	25	2,55	361	94			353	256	357
P129-3	94	18	2,61	353	53	8	3,31	326	271	340
Slow			2,65							374

At STFI Packforsk radius increment (Figure 38), wood density (Figure 39), early wood density (Figure 40), latewood density (Figure 41), latewood % (Figure 42) and density distribution (Figure 43) were measured by Silviscan.

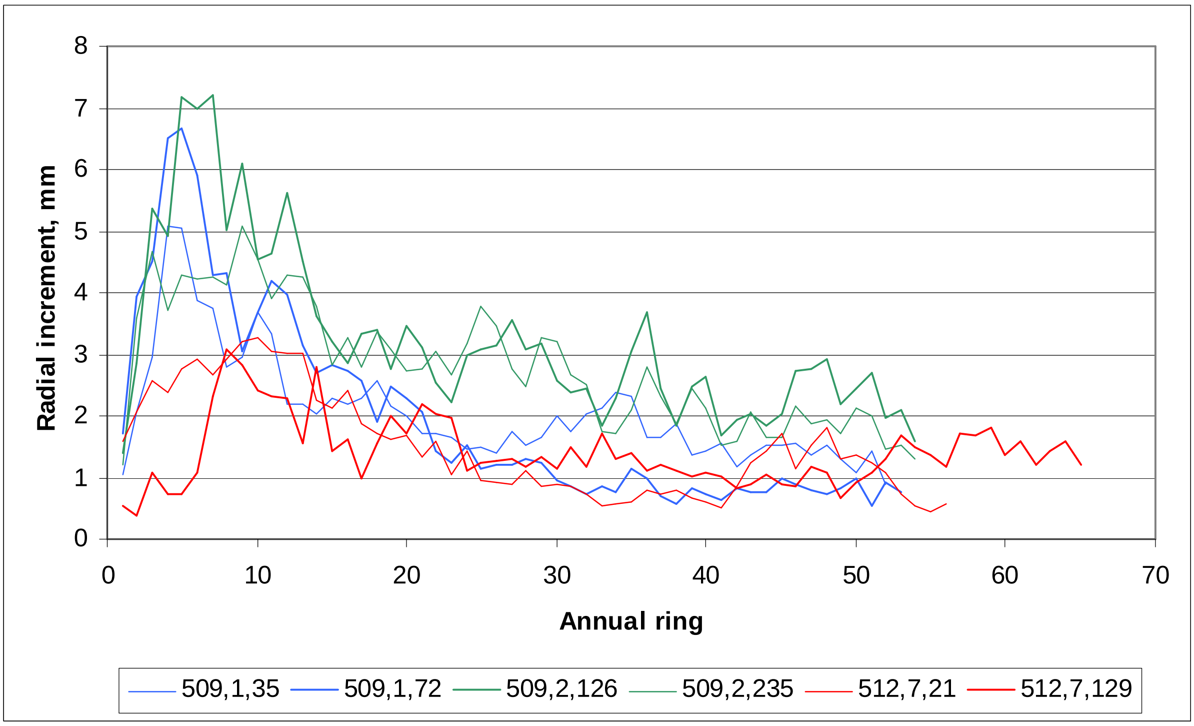

Figure 38 . *Annual growth in the direction of radius The first annual ring is the nearest in the core.*

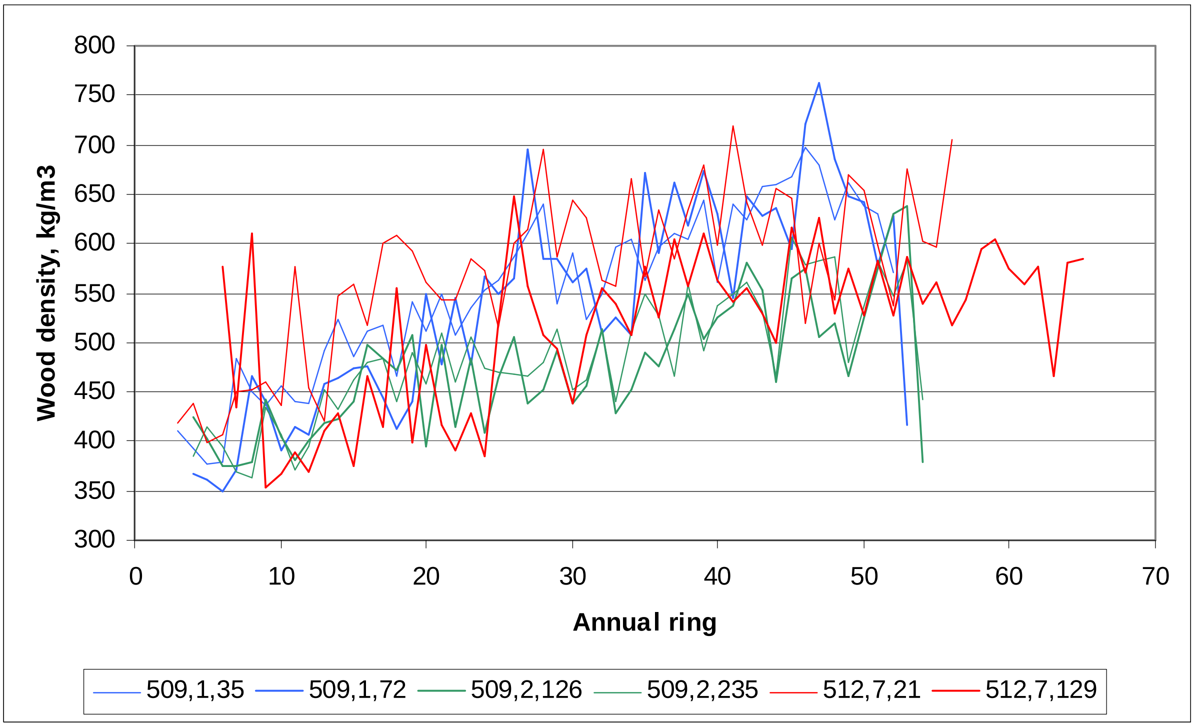

Figure 39. *The density in the direction of radius.*

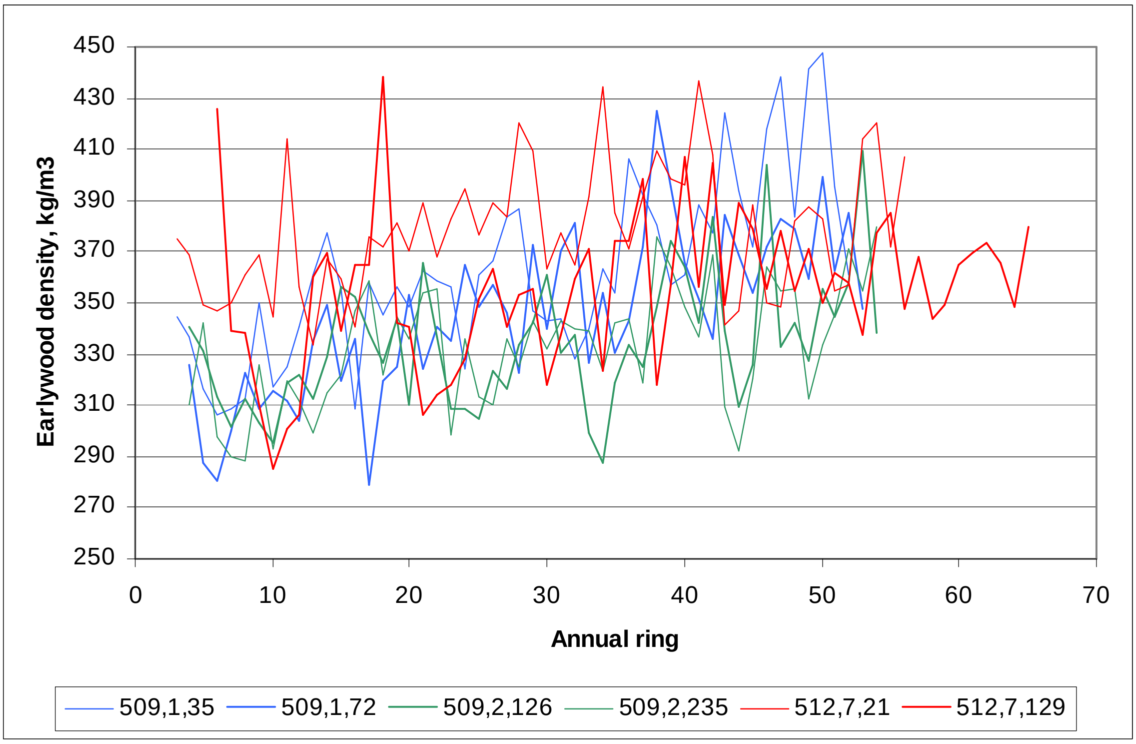

Figure 40. The density of early wood.

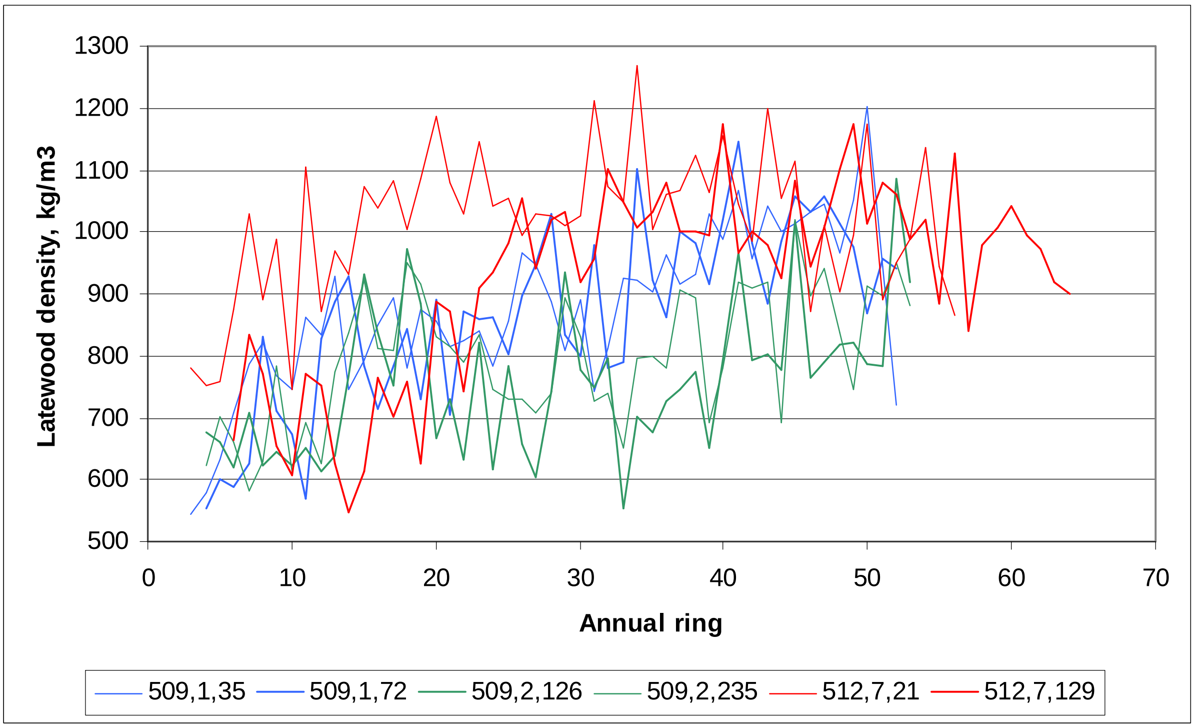

Figure 41. The density of latewood.

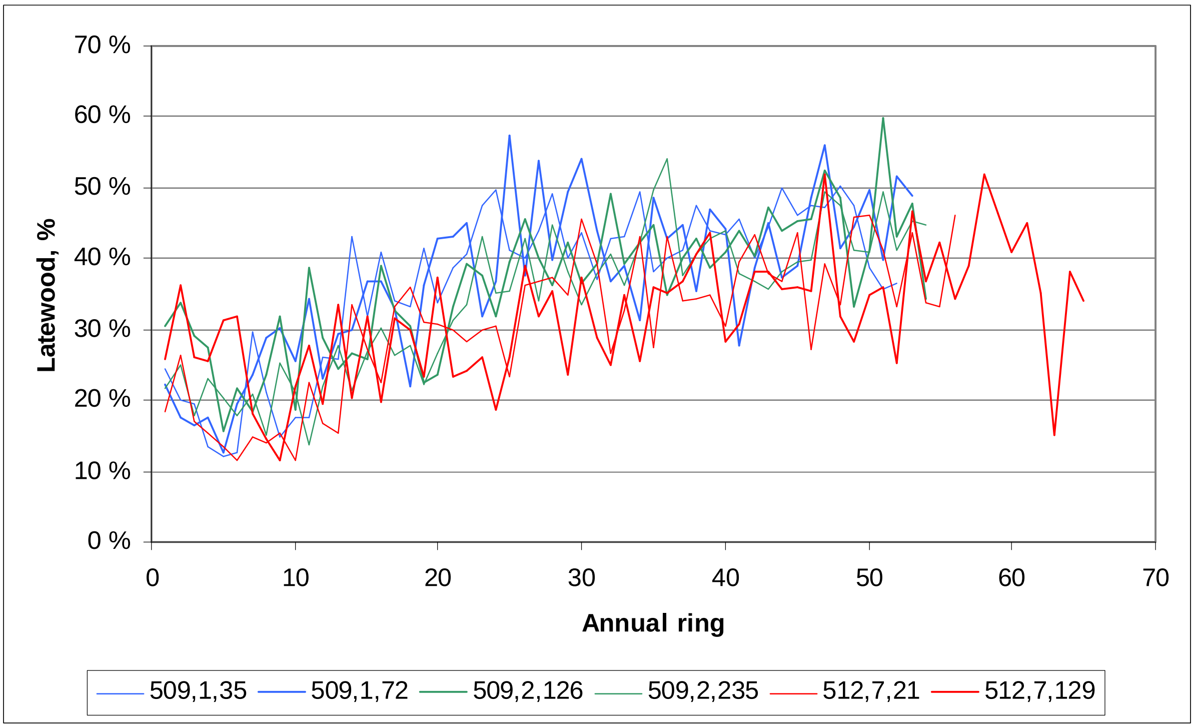

Figure 42. Latewood percentage.

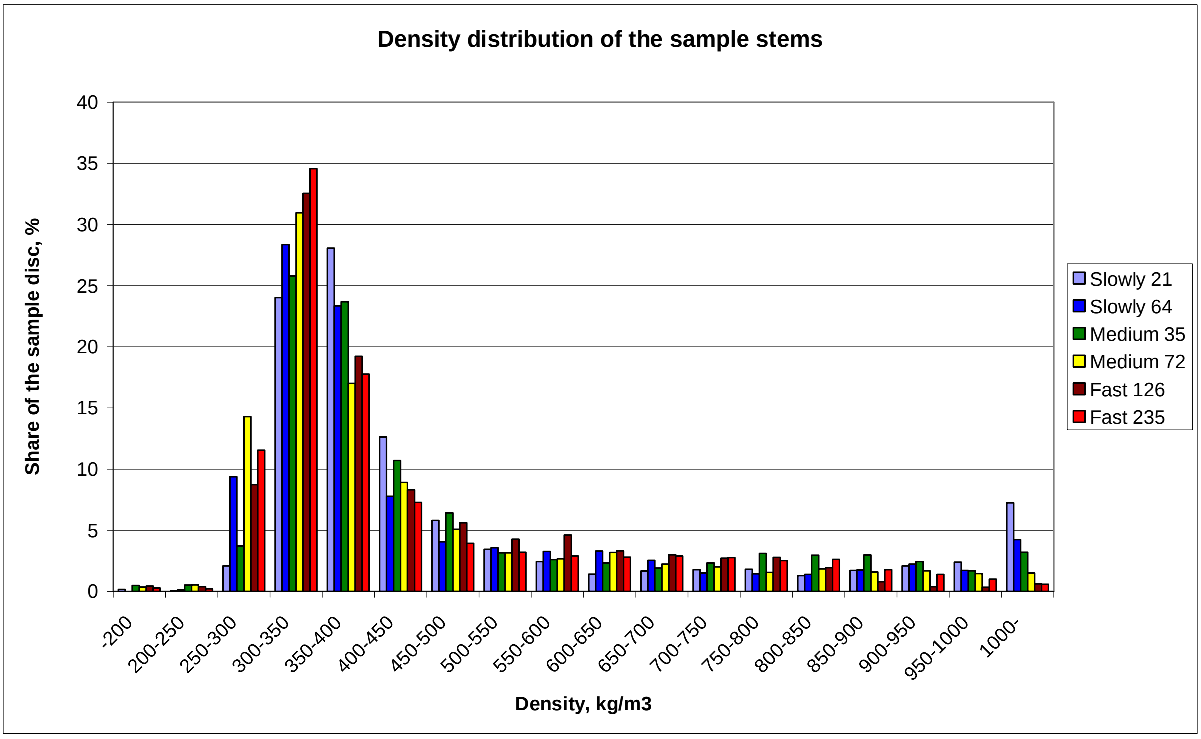

Figure 43. Density distribution of different trees. Analysed by Silviscan at STFI.

Table 7. Fibre properties of the sample trees.

Growth rate	Length Weighted Average Length	Length Weighted Average Width	Length Weighted Average Shape	Kink/mm	Kink/fiber	Kink Angle	Length Weighted Average Bendability	Fibre length classes 0.0-0.2 mm	0.2-0.5 mm	0.5-1.2 mm	1.2-2.0 mm	2.0-3.2 mm	>3.2 mm	Coarseness
	mm	µm				°		%	%	%	%	%	%	µg/m
Slow	2,51	36,2	87,1	0,23	0,42	66,7	9,45	5,5	4,0	6,7	18,8	43,6	21,3	147
Medium	2,59	34,9	86,7	0,23	0,44	66,9	9,8	5,4	3,5	5,7	16,5	45,9	22,9	135
Fast	2,40	33,8	87,0	0,25	0,43	65,9	9,8	5,0	3,8	7,5	21,1	46,5	16,0	137

Fractionation of wood

Before fractionation, the pulp chips were processed into pin chips. The particle thickness was analysed by mechanical screen and the distributions are presented in the Figure 14. Less than 8 % of the pin chips are thicker than 2 mm. 42–50 % belongs to classes 0–1 mm and 1–2 mm in thickness. Only small differences, but not significant, appear in different growth rates.

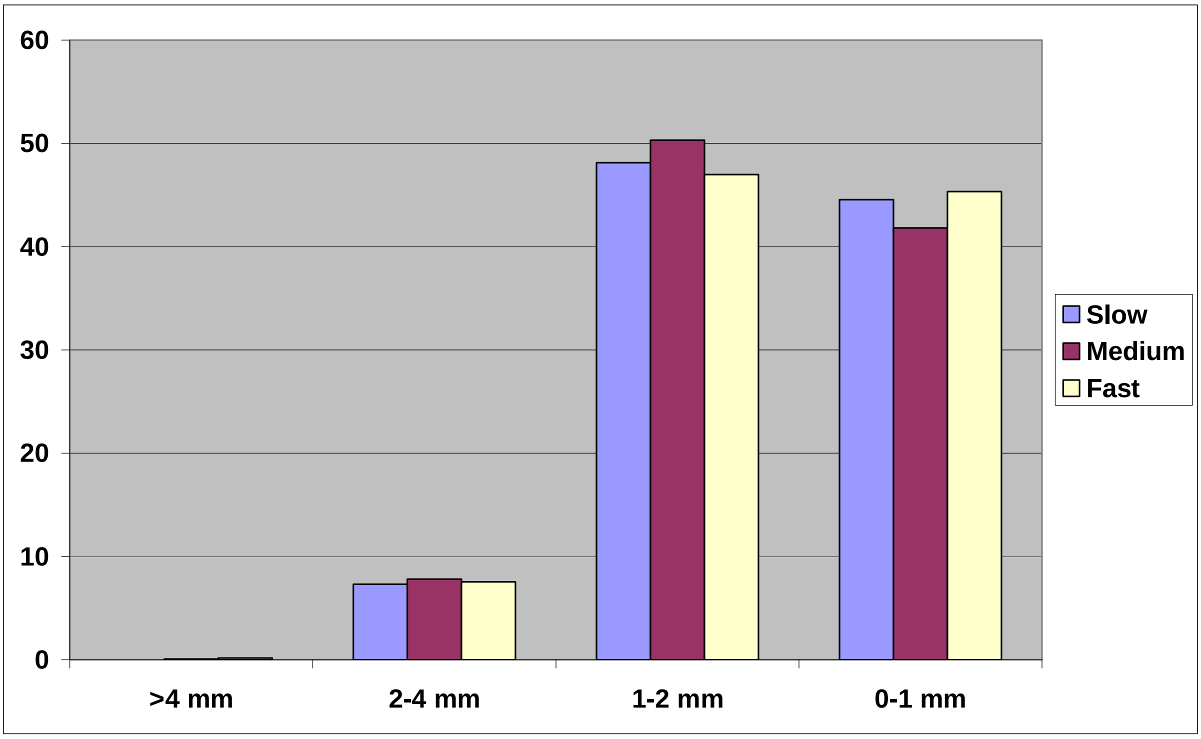

Figure 44. Particle thickness distribution of the pin chips.

Another particle size analyse was done by image analysis. The length and width distributions are presented in Figures 45-49. Original pin chips are rather similar in length and width. The greatest difference is between latewood fraction from slowly grown wood and early wood fraction from fast grown wood. Early wood fractions are longer and thicker than latewood fractions.

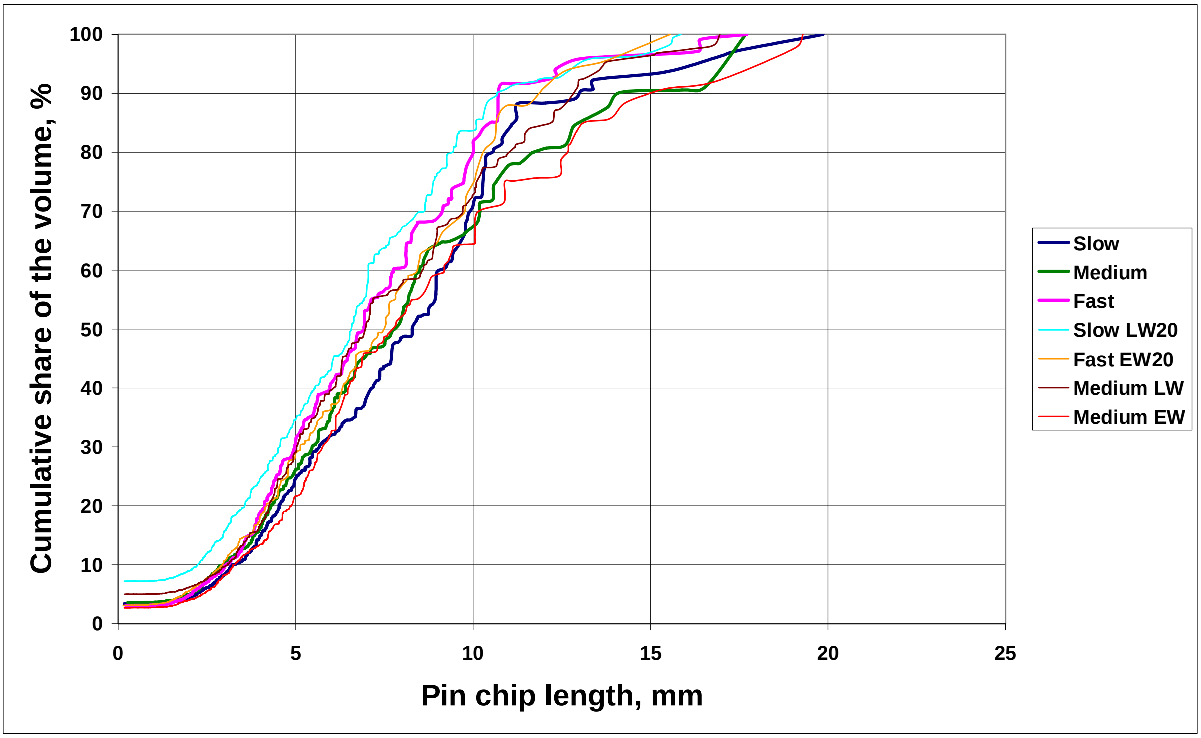

Figure 45. *Length of the pin chips.*

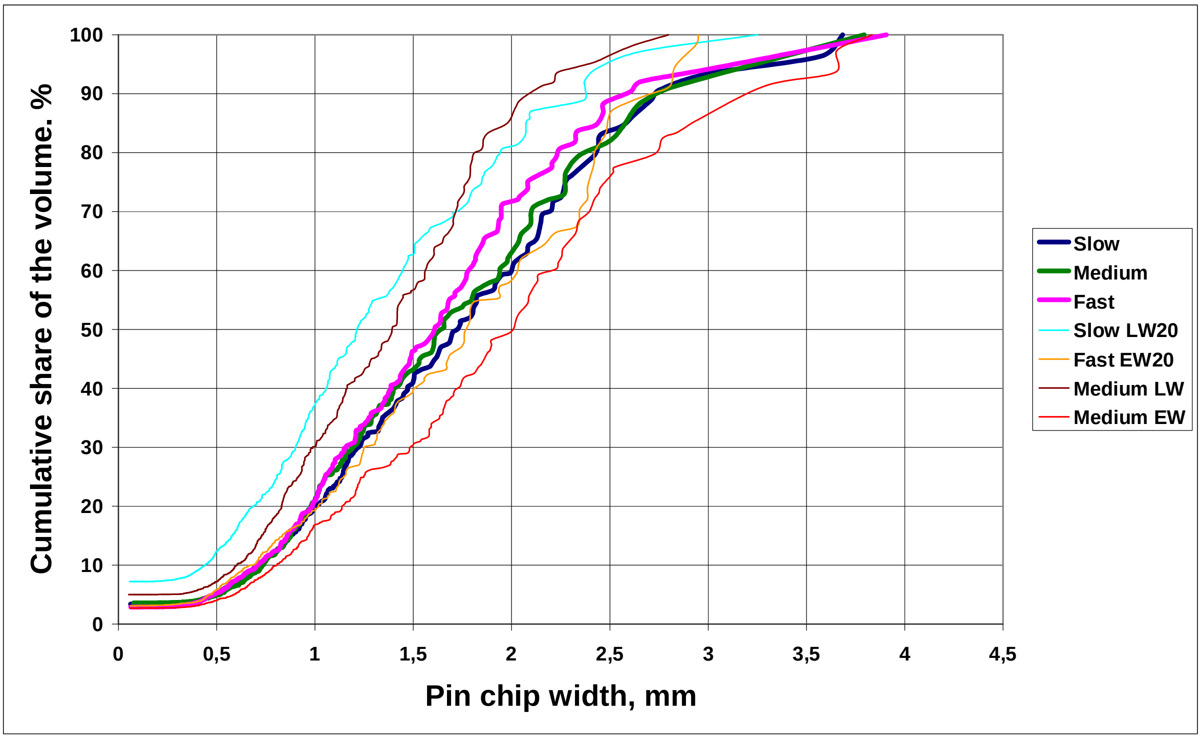

Figure 46. *Width of the pin chips.*

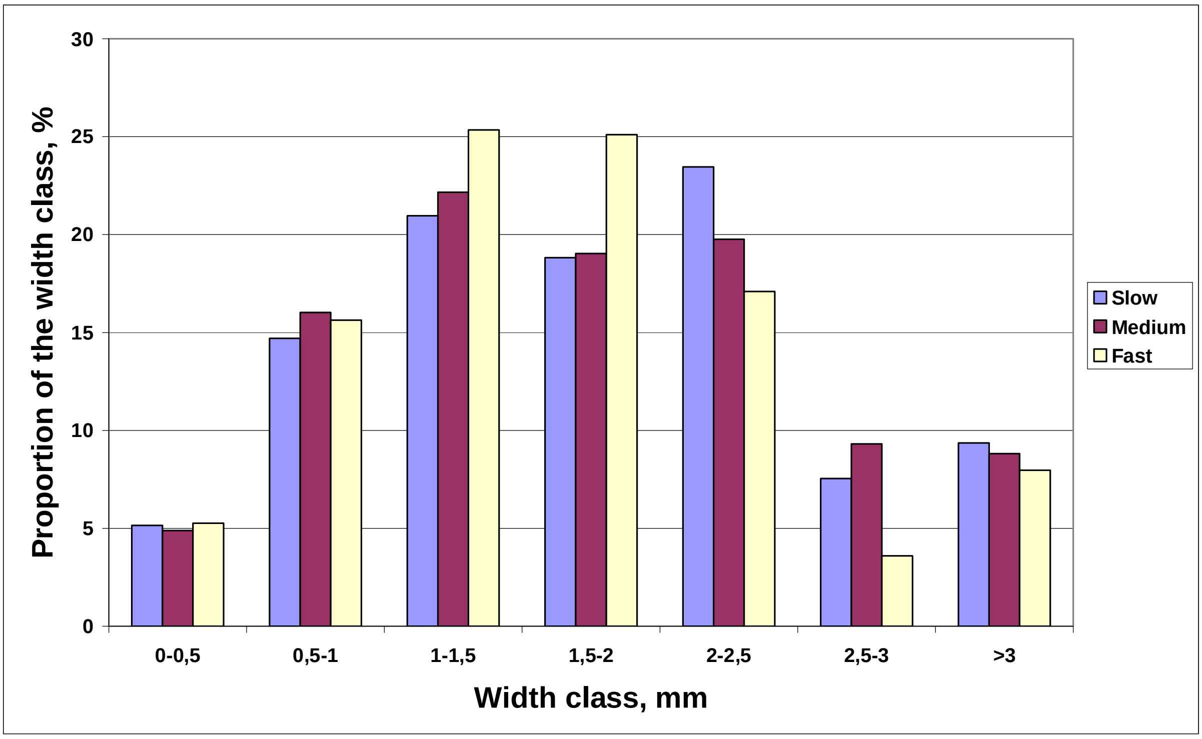

Figure 47. Width of unfractionated pin chips.

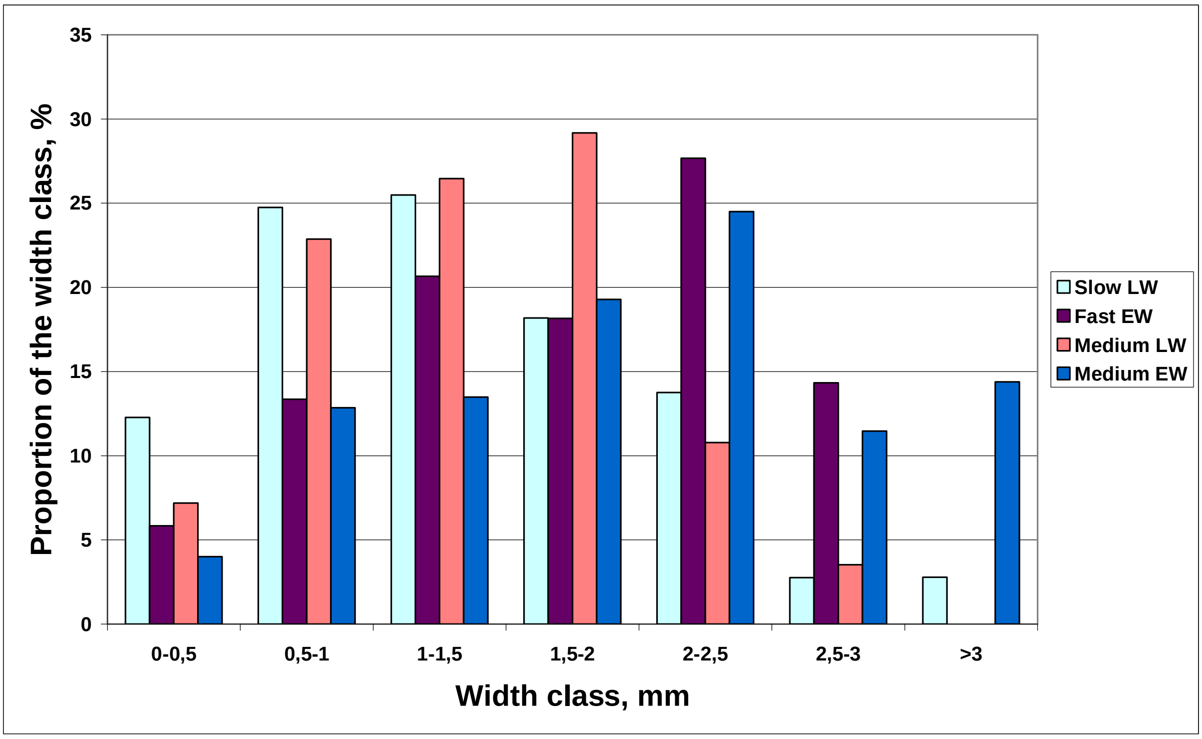

Figure 48. Width of fractionated pin chips.

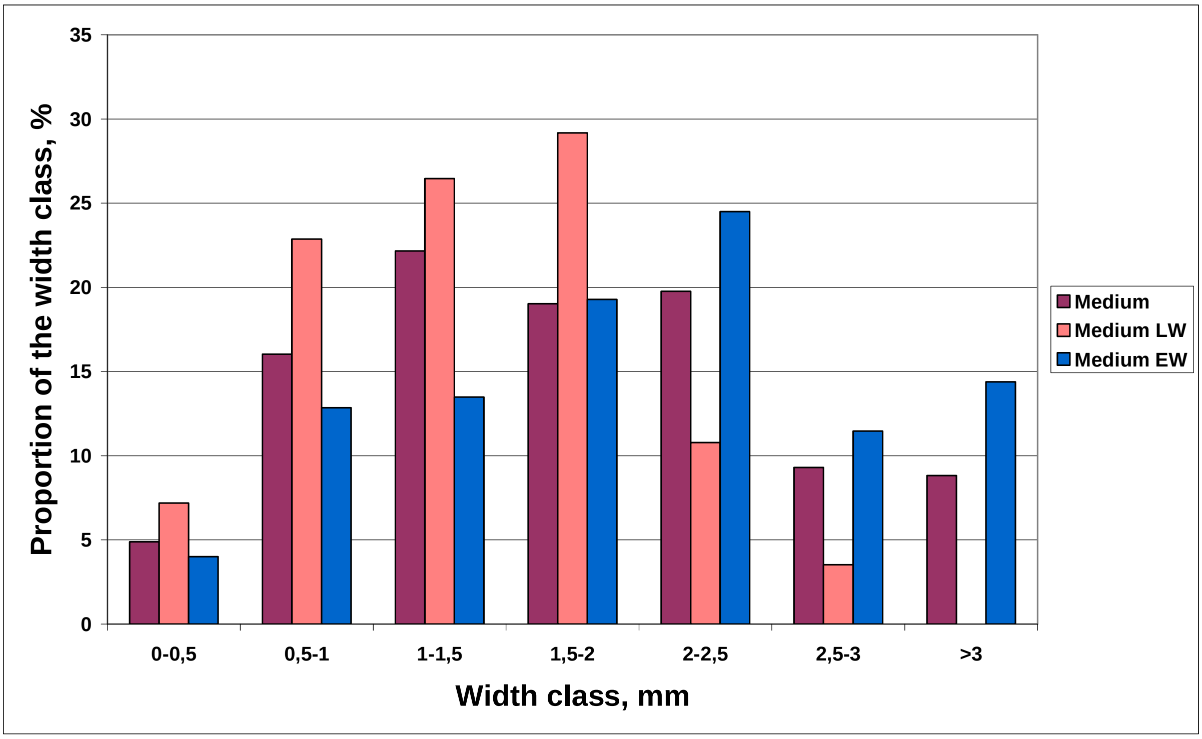

Figure 49. Width of fractionated medium grown pin chips.

Densities of pin chips were measured in 0,5 x 0,5 x 0,5 m box. The results are shown in Table 8. The results are rather close to each other. The dry densities of slowly grown should be highest, but perhaps the growing conditions are different to others because it is from different experiment plant.

Table 8. Densities of pin chips measured in 0,5 x 0,5 x 0,5 m box.

Growth rate	Moisture content	Green density	Dry density	Green density after 3 drop	Dry density after 3 drop
	%	kg/m3	kg/m3	kg/m3	kg/m3
Slow	54,0	282	130	322	148
Fast	55,1	291	131	342	154
Medium	52,3	278	133	332	158

Preliminary studies were done in static beaker, Figure 50. Medium density had a clear effect on sinking. Based on the preliminary studies the conditions of dynamic trial were chosen. The final conditions were chosen from the pre-trials with dynamic equipment. The trial conditions and main fractionation result are presented in the Table 9.

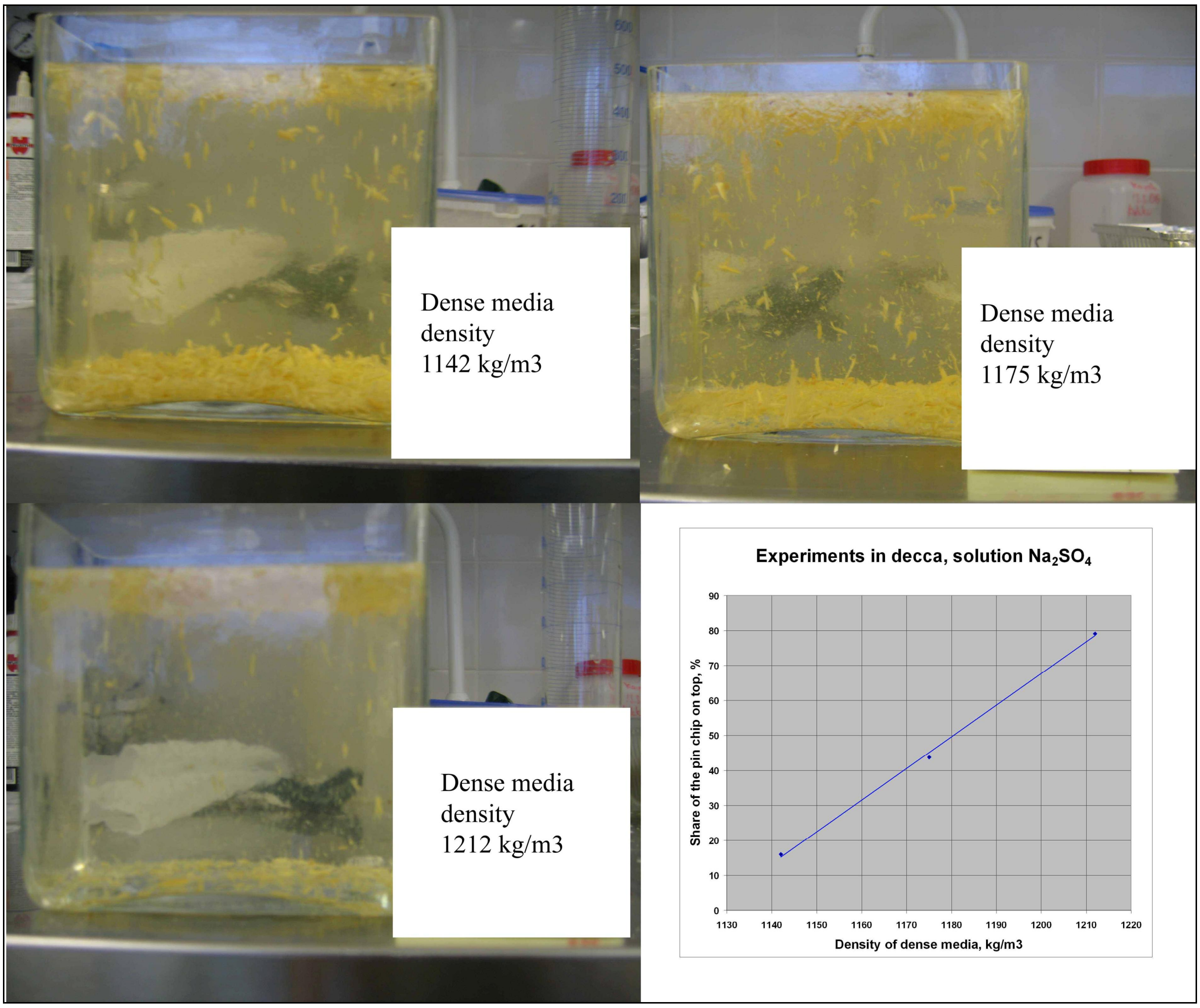

Figure 50. Experiments were done in static beaker by Na_2SO_4 solution. The amount of solution was 1.5 litres and pin chips 20 g dry.

Table 9. Fractionation conditions and main results.

Experiment	Material	Valve position	Density of NA_2SO_4 solution	Cyclone angle	Velocity of Dense media	Moisture content of feed pin chips	Share of EW fraction	Capasity
nro		°	kg/m3	o	litre/s	%	% (DS)	kg (DS)/h
4	P35 + P72 medium	47	1190	20	2,68	69,3	88	7,5
5	P35 + P72 medium	47	1160	20	2,68	71,0	75	8,2
6	P35 + P72 medium	47	1113	20	2,68	71,0	47	7,8
13	P35 + P72 medium	47	1074	20	2,68	71,0	17	6,9
7	P126 + P235 fast	47	1115	20	2,67	74,8	54	6,8
8	P126 + P235 fast	47	1075	20	2,68	74,8	22	7,8
9	P126 + P235 fast	47	1147	20	2,67	74,8	74	9,2
10	P21 + P129 slow	47	1157	20	2,67	73,2	81	8,0
11	P21 + P129 slow	47	1111	20	2,68	73,2	50	9,2
12	P21 + P129 slow	47	1072	20	2,67	73,2	18	7,7
14	P35 + P72 medium	47	1075	20	2,67	71,0	19	7,1
15	P35 + P72 medium	47	1158	20	2,67	71,0	76	7,4
16	P21 + P129 slow	49	1160	20	2,68	73,2	68	7,3
17	P126 + P235 fast	49	1074	20	2,68	74,8	16	7,2
KCL 1	P35 + P72 medium	49	1076	20	2,67	60,0	13	7,9
KCL 2	P35 + P72 medium	49	1166	20	2,67	60,0	62	8,3

	Basic density			Fibre length			Fibre width			Coarseness		
Experiment	Feed	Eearly wood	Latewood	Feed	Early wood	Latewood	Feed	Early wood	Latewood	Feed	Early wood	Latewood
nro	kg/m3	kg/m3	kg/m3	mm	mm	mm	µm	µm	µm	µg/m	µg/m	µg/m
4	369,0			1,85			34,8					
5	369,0	367,7	471,9	1,85	1,83	1,77	34,8	35,1	33,5	156	152	171
6	369,0	344,4	456,4	1,85	1,85	1,83	34,8	35,5	34,3	156	148	168
13	369,0	317,5	394,5	1,85	1,78	1,86	34,8	35,3	34,6	156	137	161
7	356,0	330,4	421,8	1,72	1,71	1,69	33,8	33,9	32,6	143	139	147
8	356,0	314,9	386,1	1,72	1,66	1,69	33,8	34,4	33,3	143	138	142
9	356,0	353,1	462,1	1,72	1,69	1,72	33,8	33,8	32,2	143	144	158
10	389,0	372,0	467,6	1,81	1,90	1,70	36,2	36,4	34,3	158	156	173
11	389,0	344,2	437,0	1,81	1,83	1,81	36,2	36,6	35,4	158	157	173
12	389,0	313,9	395,6	1,81	1,70	1,79	36,2	36,2	35,5	158	148	164
14	369,0	320,0	418,8	1,85	1,78	1,87	34,8	34,7	34,0	156	129	143
15	369,0	382,2	476,9	1,85	1,88	1,80	34,8	34,6	33,6	156	150	159
16	389,0	364,4	426,2	1,81	1,81	1,75	36,2	35,5	34,9	158	154	167
17	356,0	311,0	371,6	1,72	1,59	1,64	33,8	34,8	33,3	143	124	143
KCL 1	369,0	320,9	403,5	1,85	1,71	1,87	34,8	34,9	34,4	156	138	163
KCL 2	369,0	371,9	441,9	1,85	1,74	1,70	34,8	34,7	34,0	156	155	170

Basic density of fractions and original pin chips is presented in Figure 51 and 52. The largest difference in basic density was 165 kg/m^3. That is between early wood fraction from fast grown wood and latewood fraction from slowly grown wood. In original logs, the greatest basic density difference was between fast and slowly grown logs, and that was 33 kg/m^3.

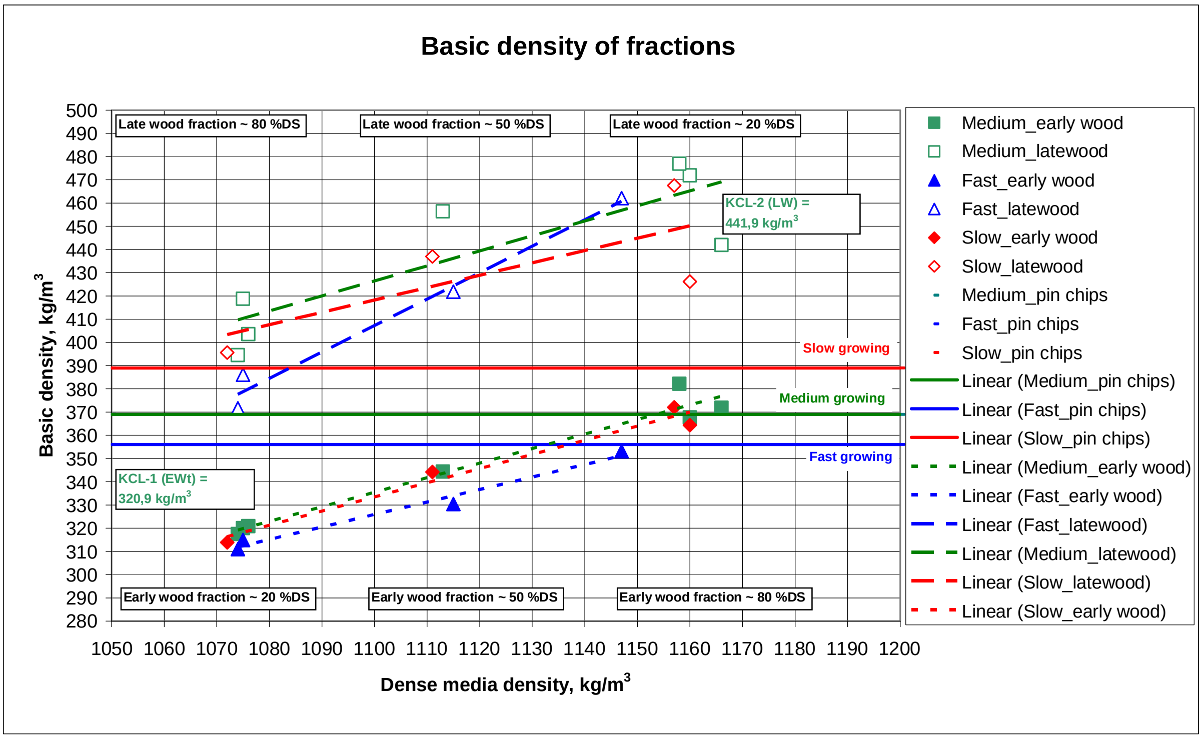

Figure 51. Basic densities of fractions versus dense media density.

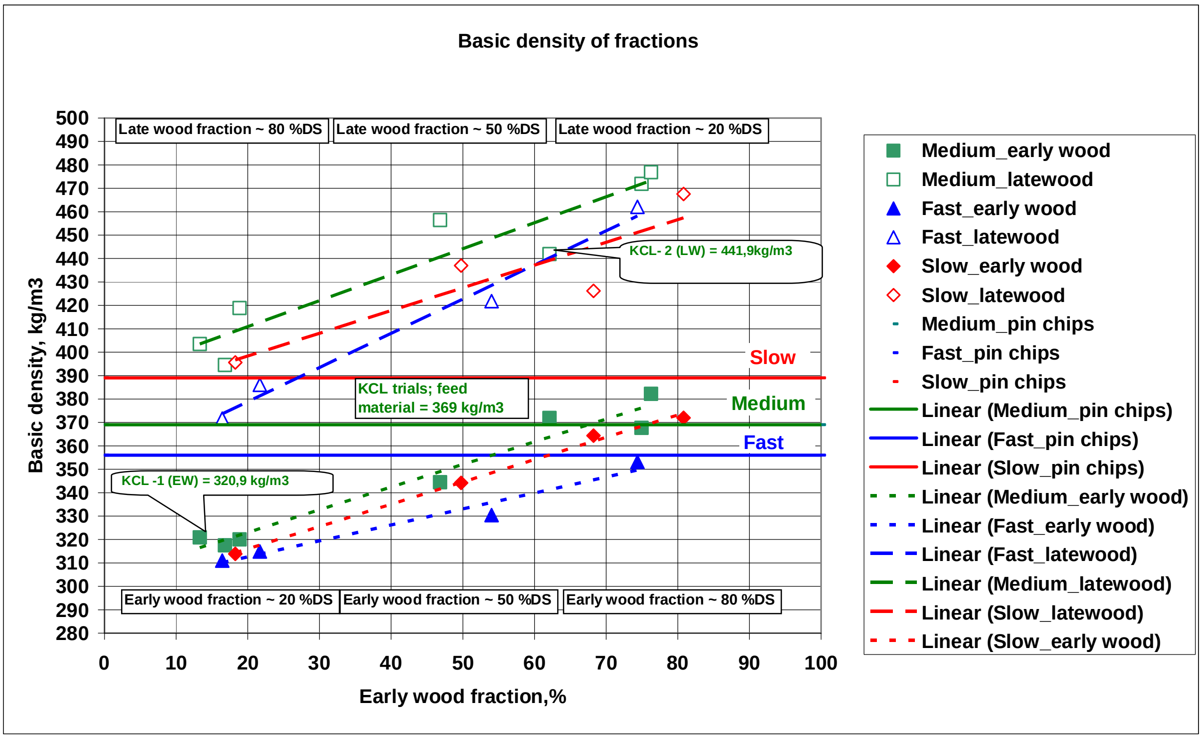

Figure 52. Basic densities of fractions versus separated early wood fraction.

Coarseness values of the fractions and original pin chips are presented in the Figure 53. The difference of coarseness value in one stage fraction varies between 4-25 µg/m. The largest difference in coarseness 49 µg/m, was noticed between early wood fraction from fast grown wood and latewood fraction from slowly grown wood. In original logs, the largest coarseness difference was between fast and slowly grown logs, and that was 15 µg/m. The results are rather logical, because in the most cases the one fraction have lower coarseness value than the original pin chips and the another fraction has higher coarseness value.

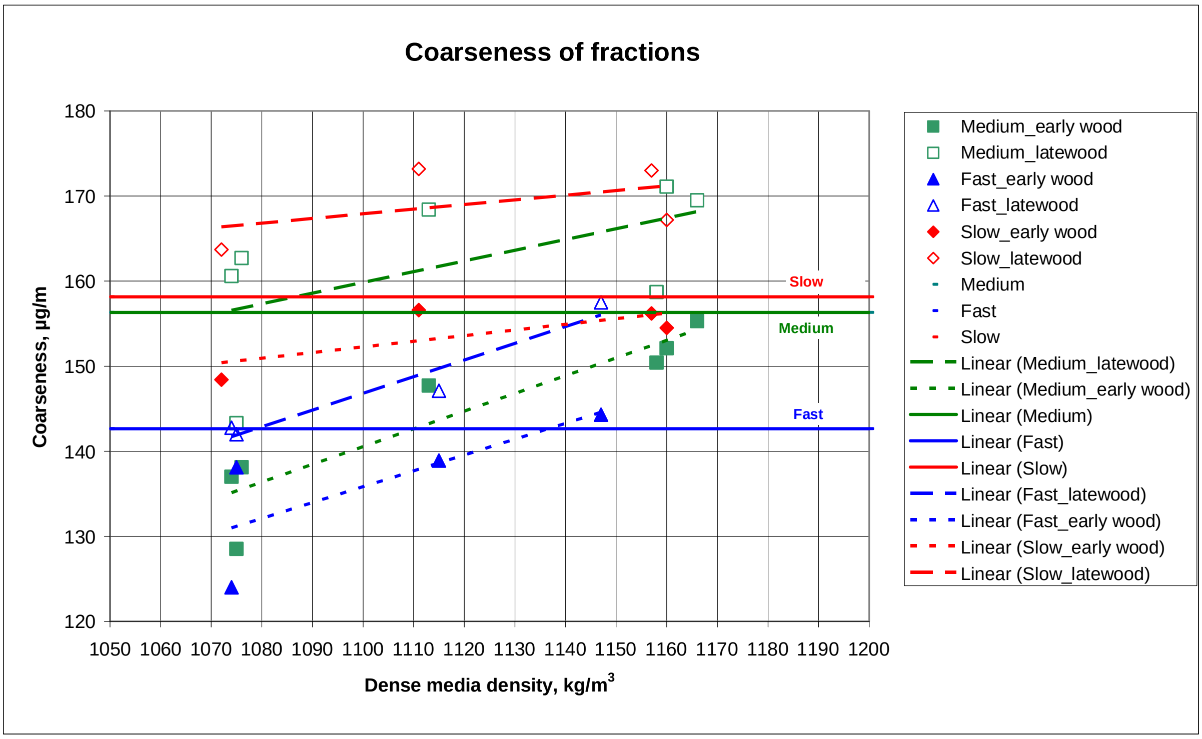

Figure 53. Coarseness of fractions versus dense media density.

The fibre length results of the fractionation trials are presented in the Figure 54. The results are not logical in the cases when the both fraction have shorter fibre length than the original pin chips. However, differences are small and inside the sampling and analysis limits.

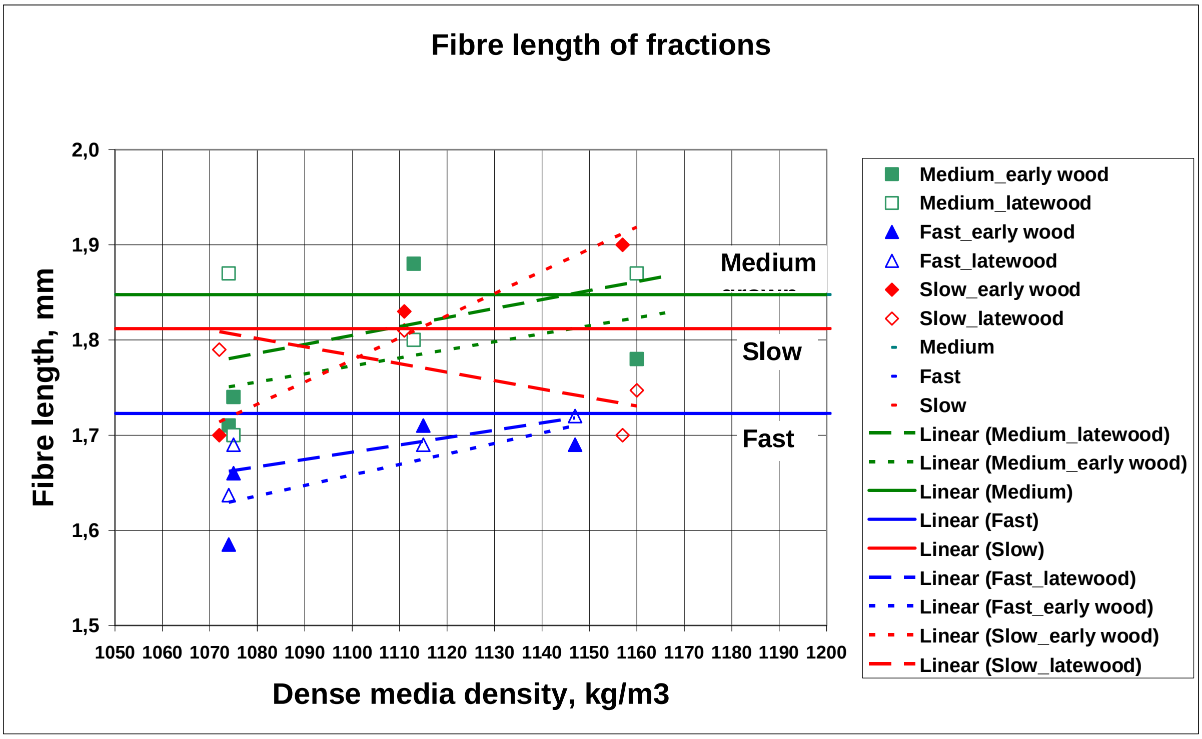

Figure 54. *Fibre length in fractionation trials.*

The fibre width results of the fractionation trials are presented in the Figure 55.

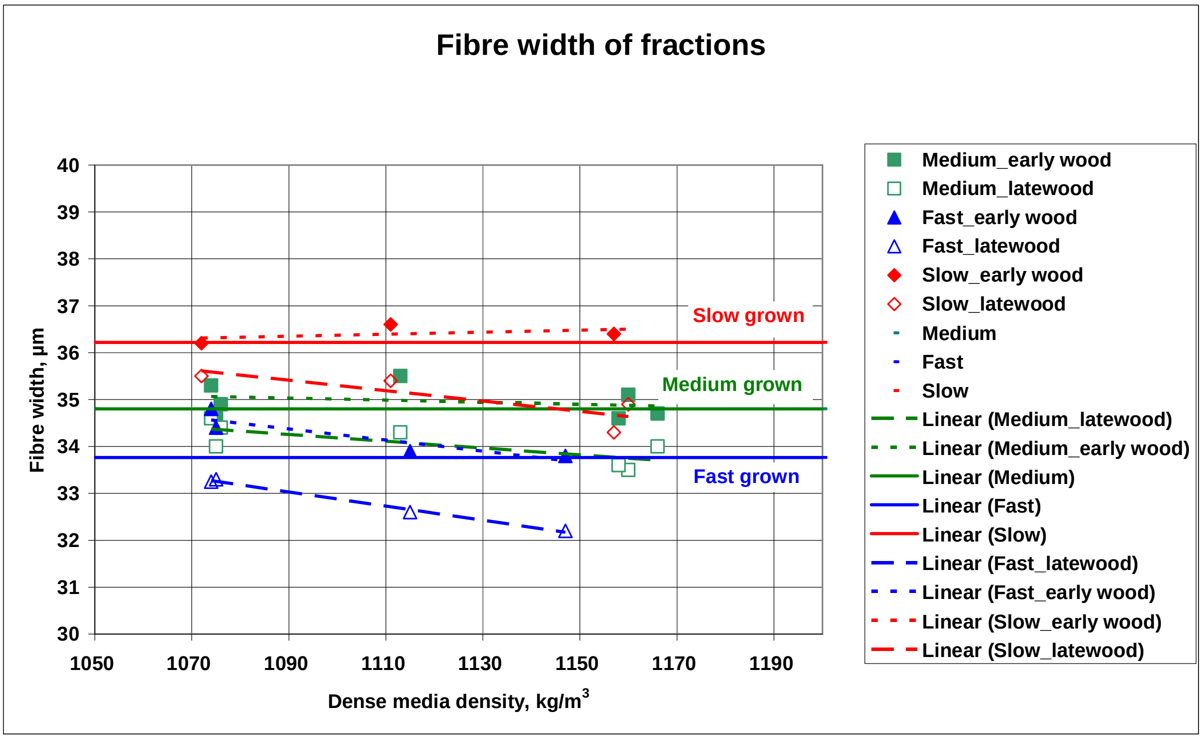

Figure 55. *Fibre width in fractionation trials.*

Mechanical pulping experiments

Specific energy consumption (SEC) of different growth rate pine samples in TMP-refining is presented in the Figure 56. Refining of fast grown pine consumes more energy than slowly grown.

In Figure 57, is compared the SEC of medium grown pine and its early and latewood fractions. The differences are very small, but it seems that refining of early wood fraction consumes more energy than latewood fraction. The result is analogous with the result of refining different growth rate pin chips.

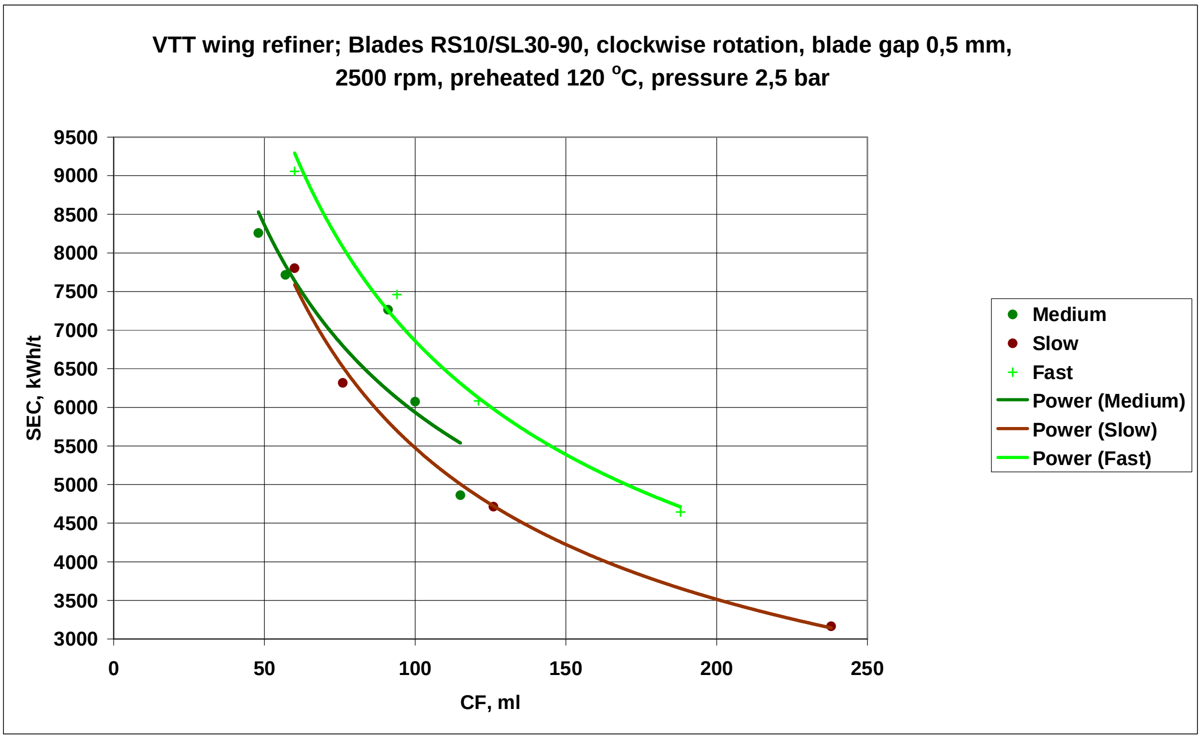

Figure 56. SEC in refining different growth rate pine pin chips.

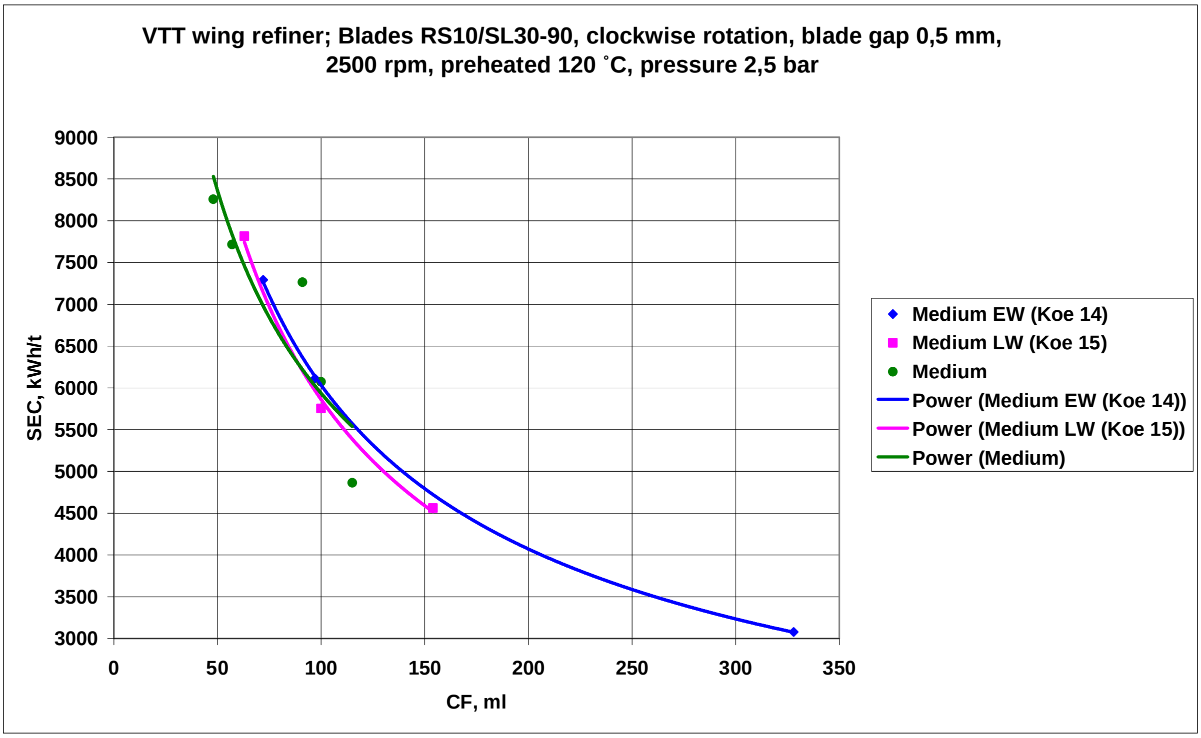

Figure 57. SEC in refining medium grown pine pin chips.

Very large specific energy consumption difference, 47 %, was achieved when comparing the refining behaviour of slowly grown latewood with that of fast grown early wood, Figure 58.

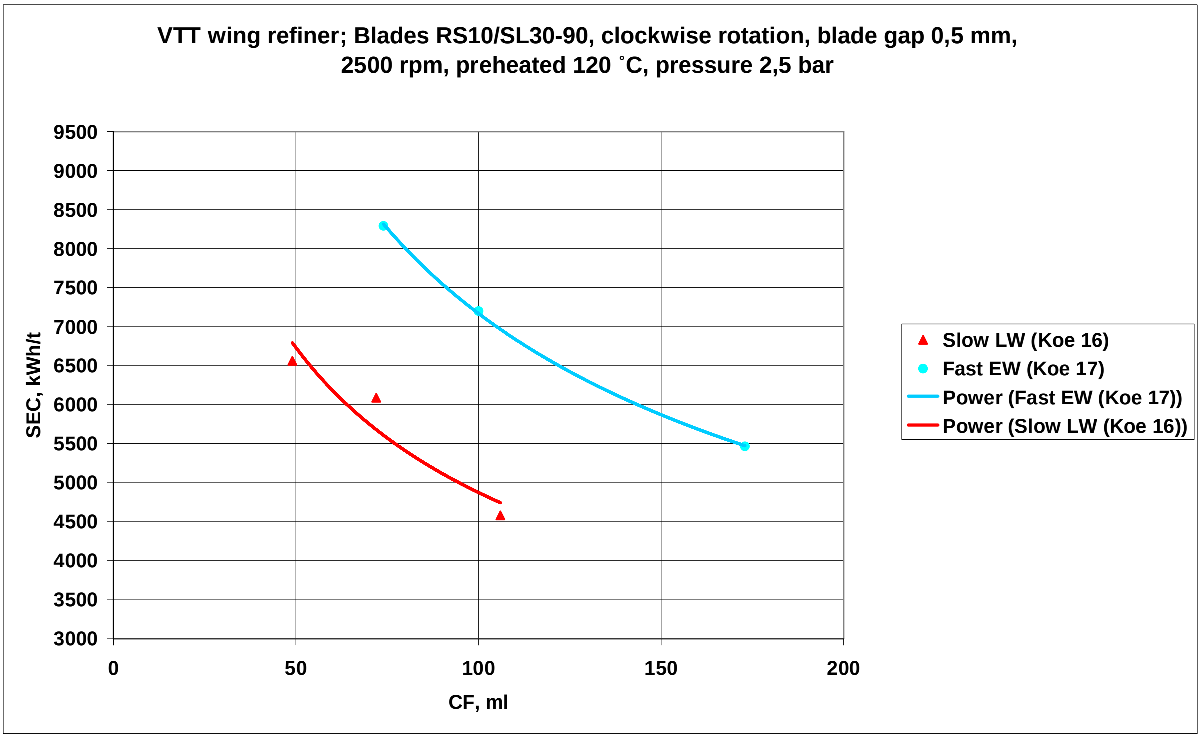

Figure 58. Maximal difference in SEC.

Growth rate and fractionation had only a very small effect on fibre length of screened pulp, Figure 59.

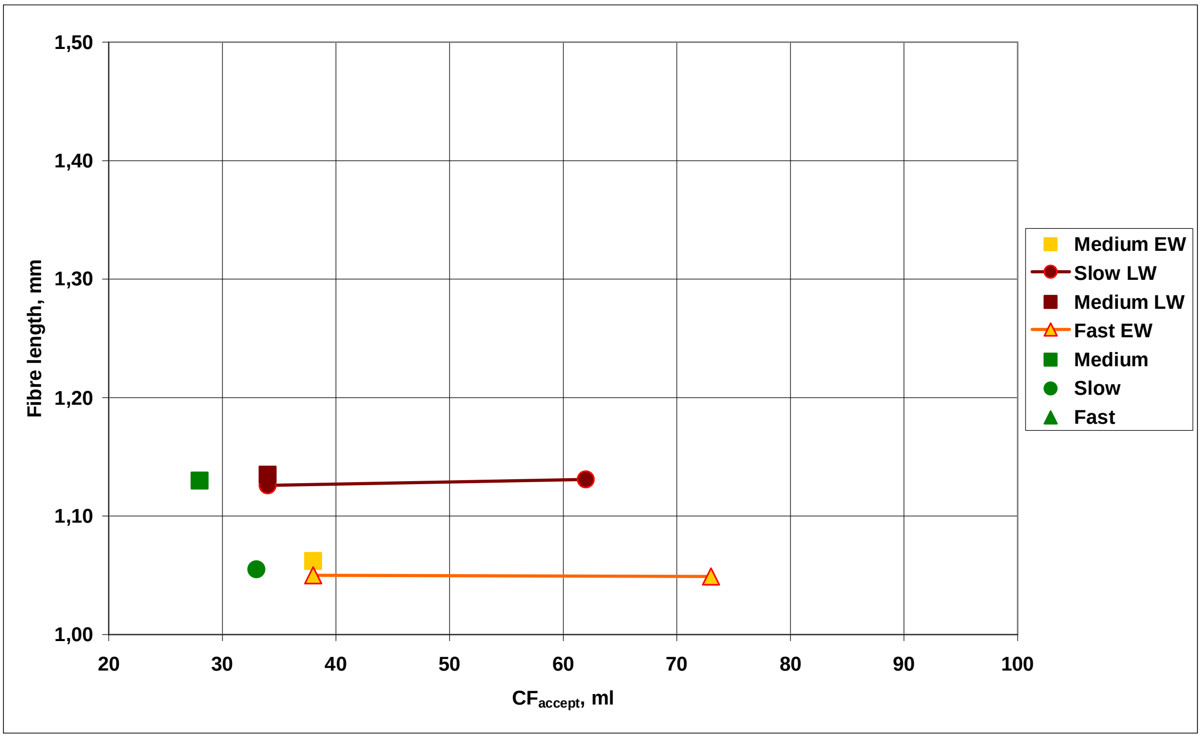

Figure 59. Fibre lengths of accepted pulps.

Refined early wood fraction and fast grown pine have higher laboratory sheet density than the sheets from slowly grown pine or early wood fraction, Figure 60.

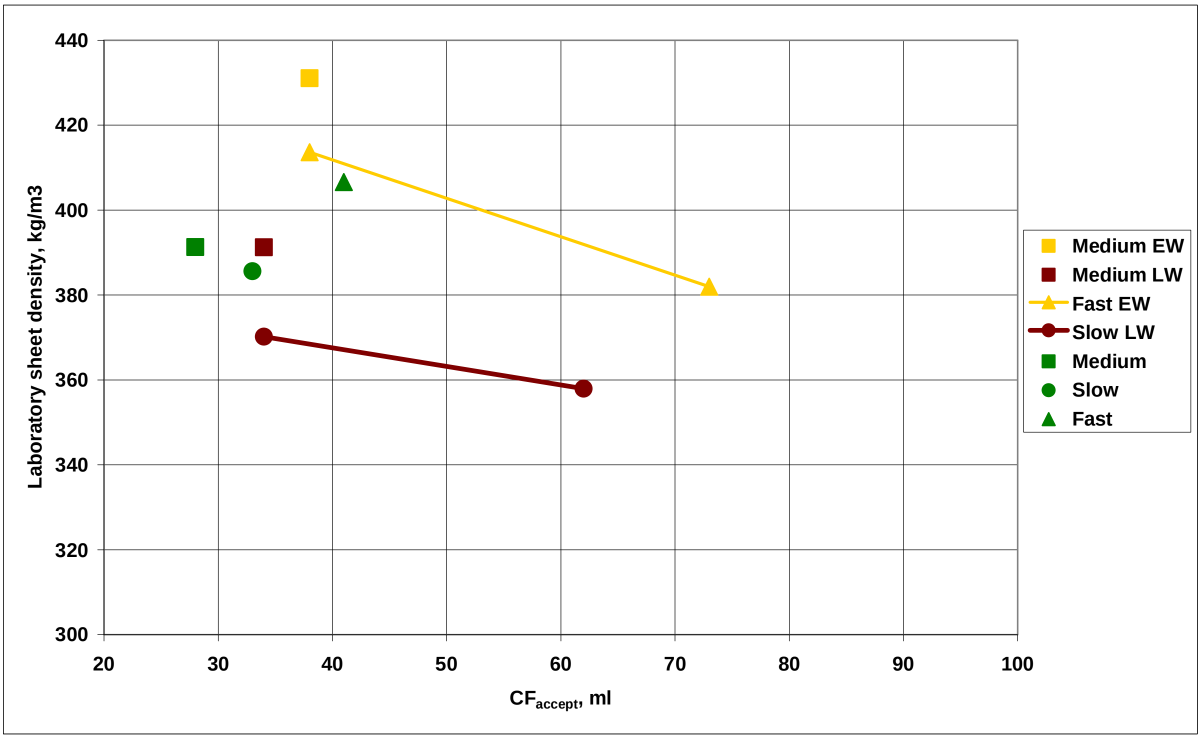

Figure 60. Density of the laboratory sheets.

Growth rate or fractionation did not have effect on shape factor, Figure 61.

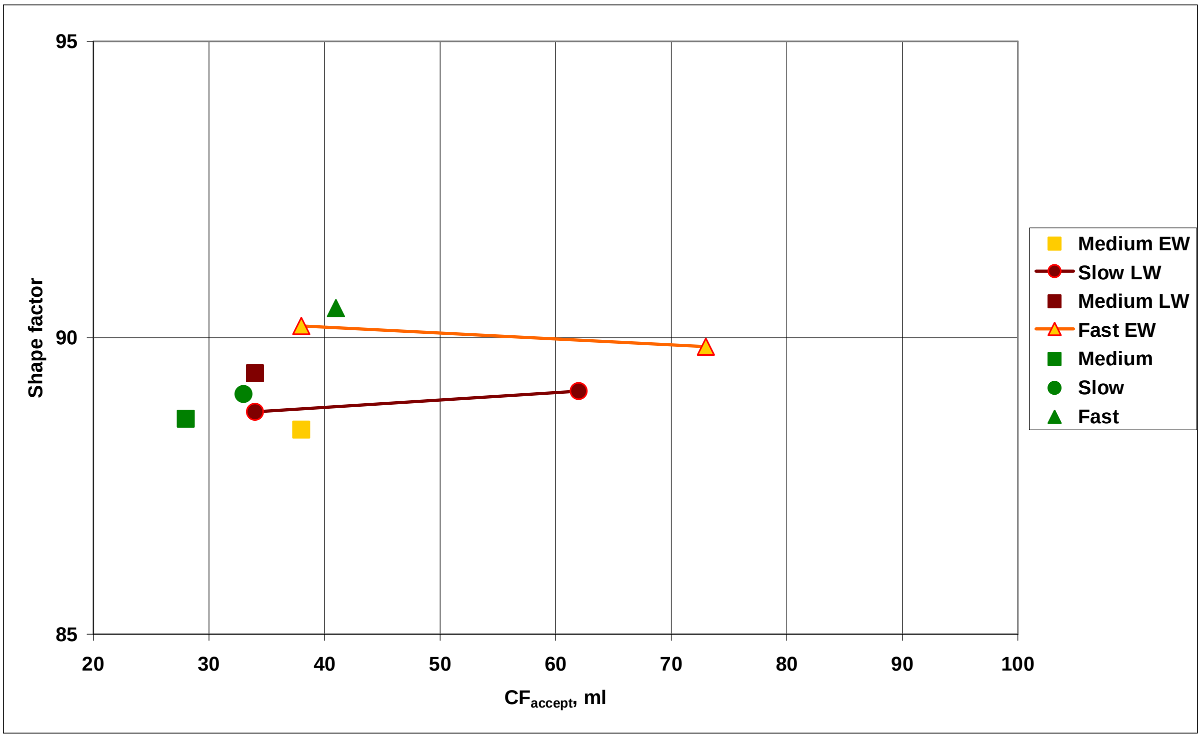

Figure 61. Shape factor.

Early wood fraction and fast grown wood had higher bendability than medium or slowly grown wood and latewood fraction, Figure 62.

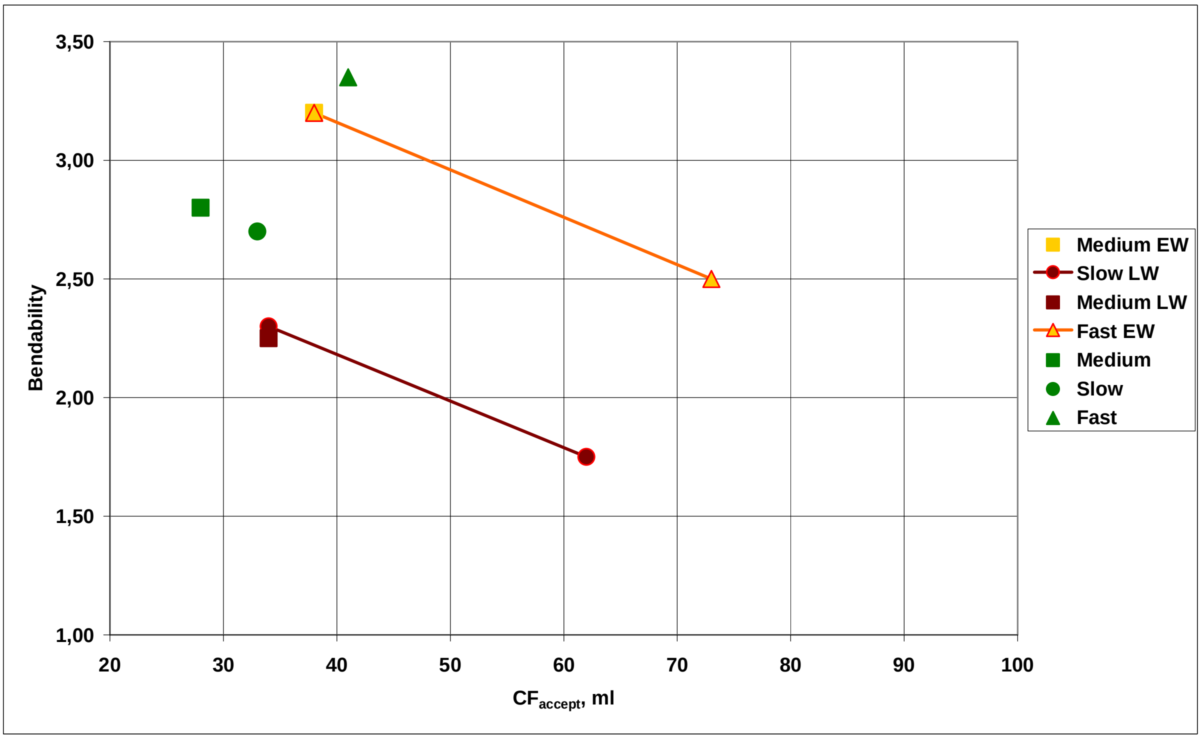

Figure 62. Bendability.

Pulp from early wood fraction had lower roughness at the same freeness level than pulps from un-fractionated or latewood fractions, Figure 63.

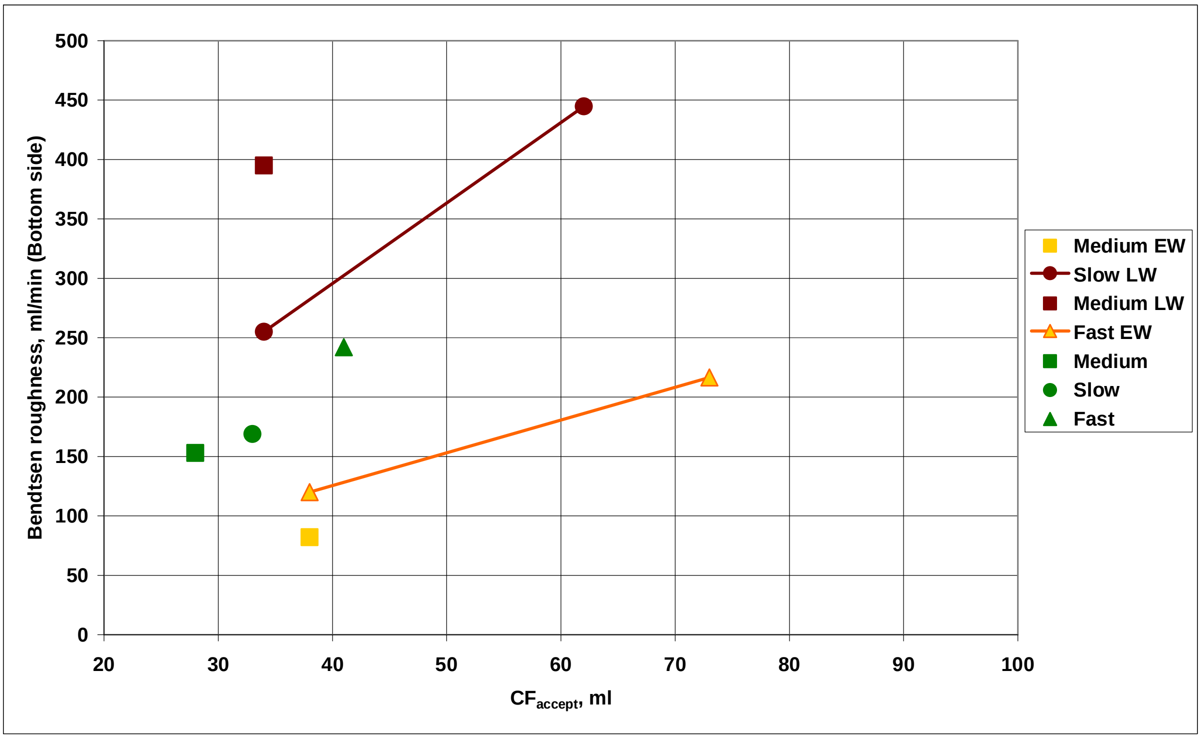

Figure 63. Bendtsen roughness.

Air permeability is in Figure 64.

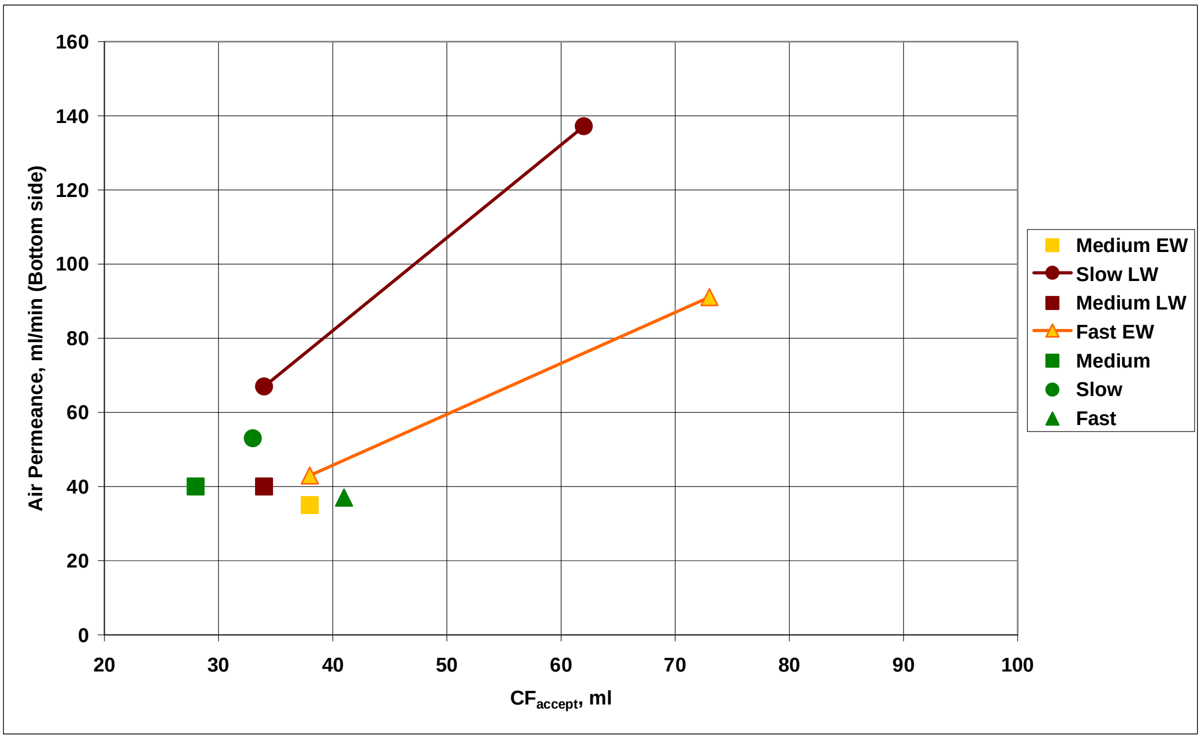

Figure 64. Air permeability.

Pulps from early wood fraction had higher tensile index at the same freeness level than pulps from un-fractionated or latewood fractions, Figure 65. The result is consistent with the literature, see Figure 7.

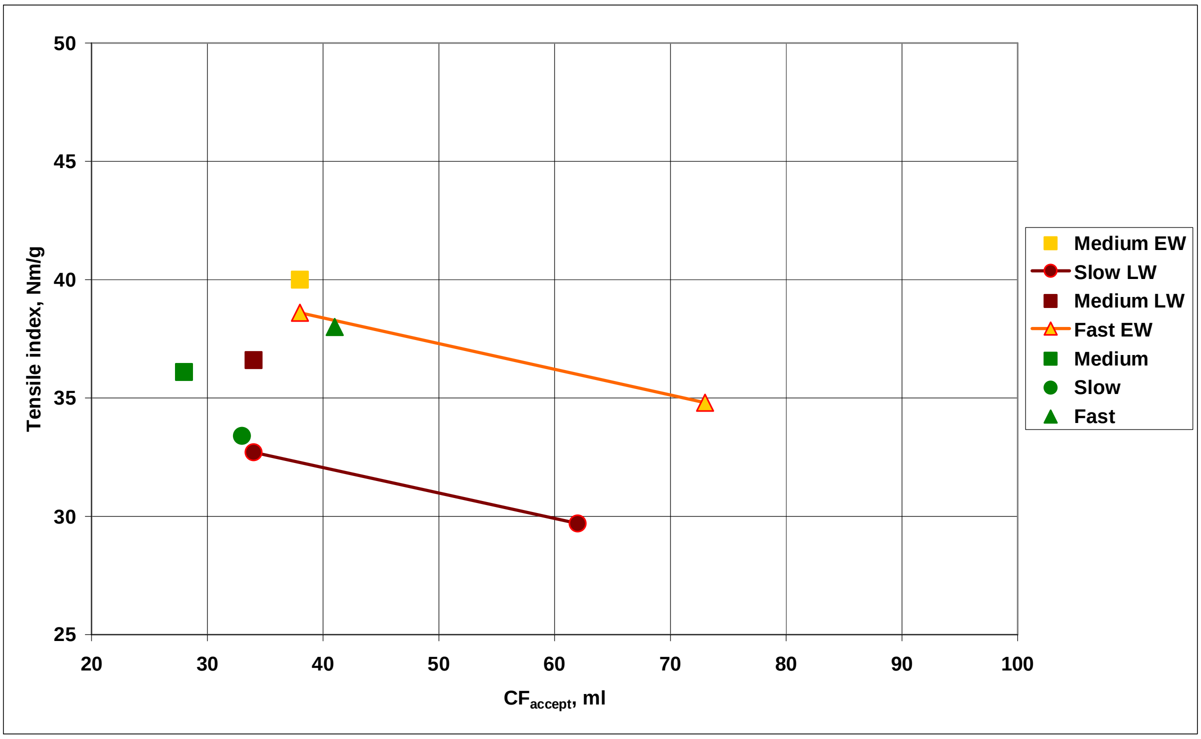

Figure 65. Tensile index.

Growth rate or fractionation did not have effect on brightness, Figure 66.

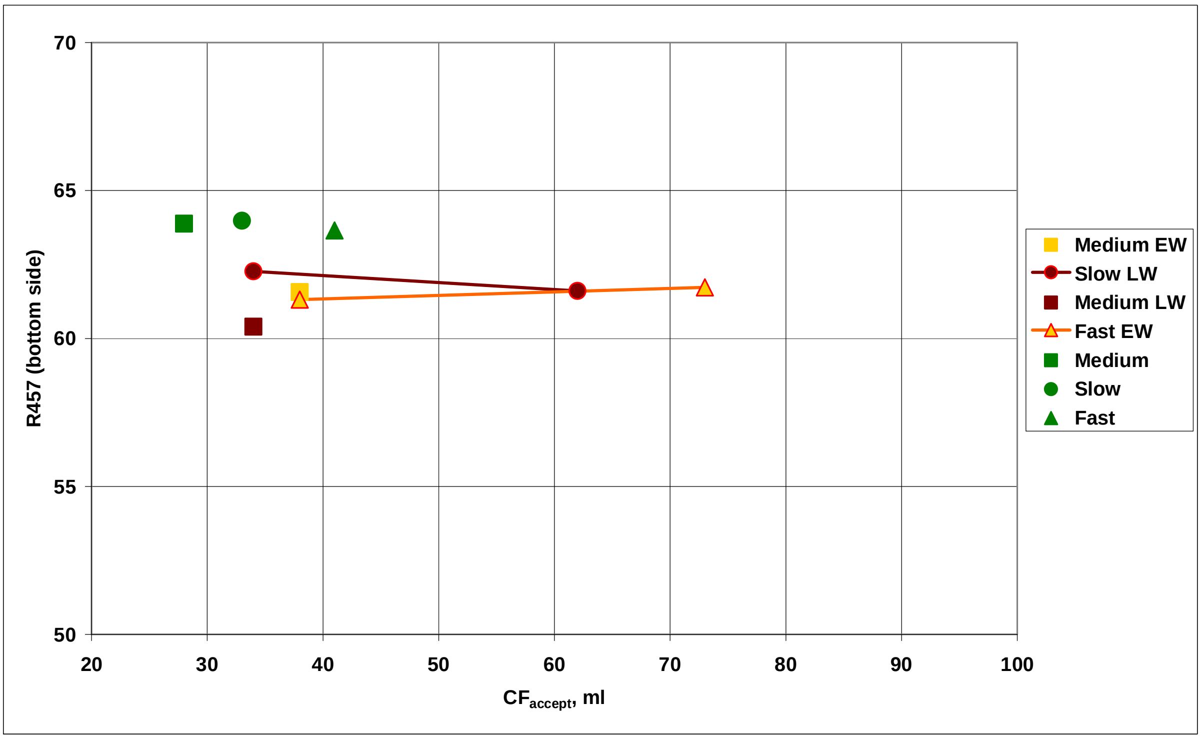

Figure 66. Brightness (R457).

Lower basic density results low roughness, Figure 67.

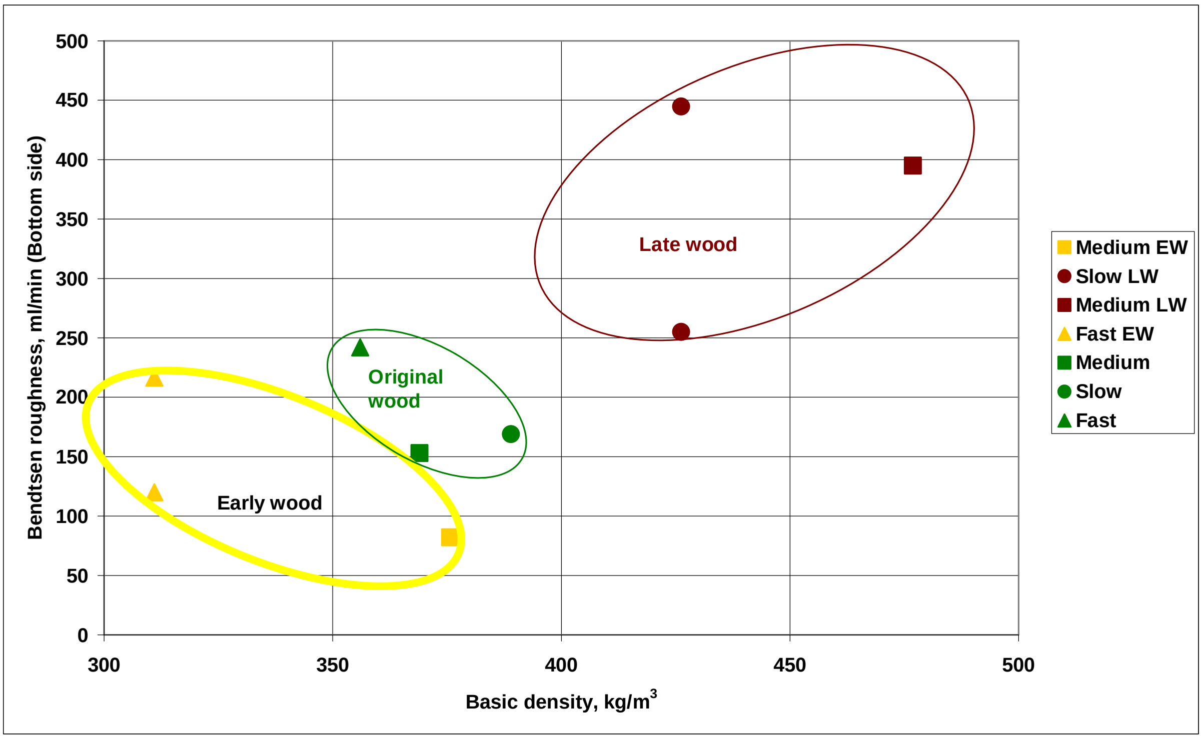

Figure 67. Bendtsen roughness vs. basic density.

Low Bendtsen roughness requires a lot of refining energy, Figure 68.

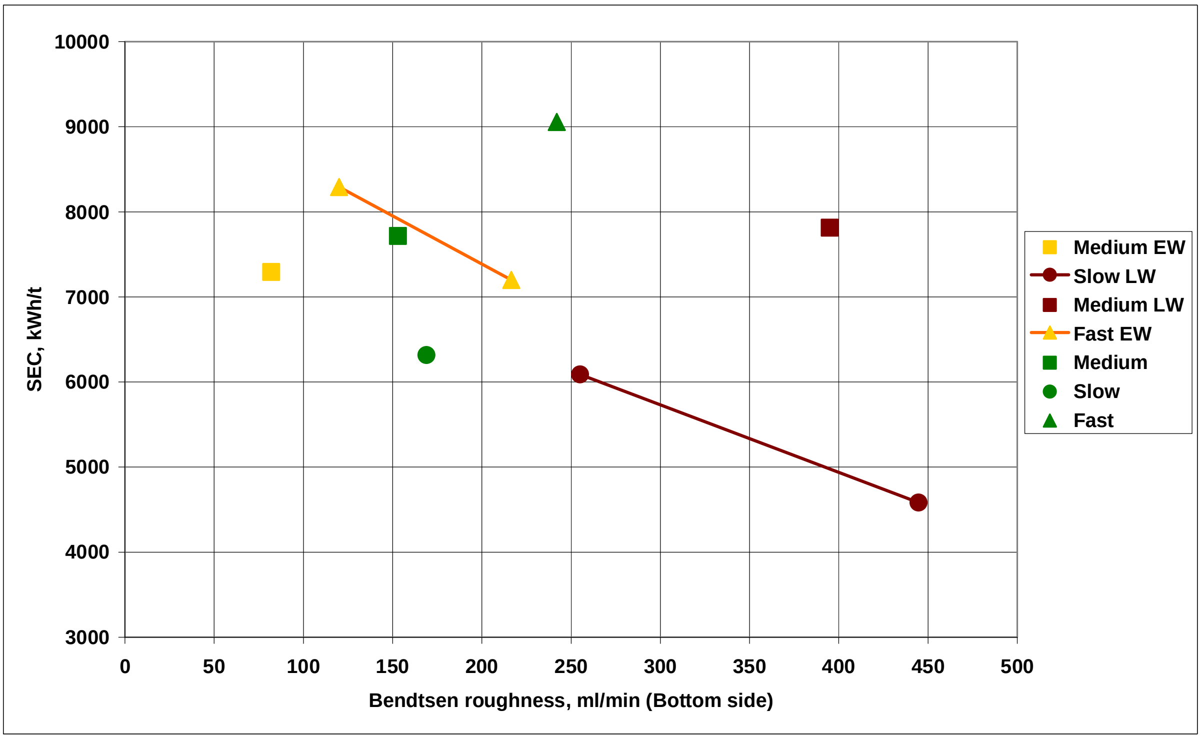

Figure 68. SEC vs. Bendtsen roughness.

Cooking experiments

The aim of the cooking experiments was to examine how the cooking of early wood and latewood rich pine fraction differs from each other.

The raw materials for the cooking trials were delivered to KCL by VTT. The samples were more like pin chips or sawdust than normal chips. The three samples and their basic densities were:

reference (ref) 366 kg/m^3
early wood rich fraction (ew) 321 kg/m^3
latewood rich fraction (lw) 442 kg/m^3

First, the H-factor series were done for all the three samples. Later, the accuracy of the yield results was checked by air drying the wood samples to have more even sample for the dry solids content determination and weighing, and thus more reliable results. In these tests the target kappa numbers were 25 and 30. The air dried samples were kept in water in room temperature for half an hour before cooking.

After the cooks, the pulps were disintegrated in a British disintegrator, washed with deionized water, screened with a TAP 03 laboratory screen (0.15 mm slot), centrifuged and homogenized. Determinations were made for total yield, screenings, kappa number (ISO 302) and brightness (ISO 2470:99). The black liquors were analyzed for pH and residual alkali (SCAN-N 33:94). From three samples (kappa 25) viscosity (SCAN-CM 15:99), fibre length (Kajaani FS300), density (ISO 5270:1998), tensile (ISO 5270:1998) and tear (ISO 5270:1998) were determined.

The cooking report is shown in the Table 10 and the pulp properties in the Table 11.

Table 10. Cooking report.

BASIC DATA				CHIP DATA		CHEMICAL CHARGE			TEMPERATURE		PULP					BLACK LIQUOR	
Order No.	Cooking No.	Date	Cooking method	Chip mark	Dry matter content	EA	Sulfidity	L/W	Cooking temp.	H-factor	Yield	Shives	Total yield	Kappa number	Brightness	pH	Residual alkali
					%	mol/kg	%	%	°C		%	%	%		%		gNaOH/l
2005-302	1744M	4.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	800	45.2	0.05	45.2	35.7	33.1	13.4	15.4
2005-302	1750M	9.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	950	44.1	0.03	44.2	28.1	34.8	13.4	15.2
2005-302	1753M	9.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	1050	43.6	0.05	43.7	24.7	35.6	13.4	13.7
2005-302	1747M	4.3.2009	Purukeitto	ref	40.0	6	35	4.5	180	1200	43.3	0.02	43.3	23.4	36.6	13.4	13.1
2005-302	1746M	4.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	800	44.1	0.02	44.2	38.8	36.8	13.4	16.5
2005-302	1752M	9.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	950	43.5	0.07	43.5	33.3	38.0	13.4	16.6
2005-302	1755M	9.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	1050	42.9	0.09	43.0	27.8	39.7	13.4	15.6
2005-302	1749M	4.3.2009	Purukeitto	ew	31.2	6	35	4.5	180	1200	42.4	0.03	42.4	24.7	41.0	13.4	13.9
2005-302	1745M	4.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	800	42.8	0.04	42.9	32.6	37.8	13.4	16.0
2005-302	1751M	9.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	950	42.0	0.06	42.1	26.8	39.8	13.4	15.6
2005-302	1754M	9.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	1050	41.7	0.10	41.8	24.5	40.7	13.4	15.0
2005-302	1748M	4.3.2009	Purukeitto	lw	40.9	6	35	4.5	180	1200	41.0	0.01	41.1	20.6	42.6	13.4	13.9
2005-302	1766M	1.4.2009	Purukeitto	ref dry	91.8	6	35	4.5	180	900	44.4	0.04	44.5	28.8	32.8	13.3	14.4
2005-302	1769M	1.4.2009	Purukeitto	ref dry	91.8	6	35	4.5	180	1050	43.8	0.06	43.8	25.7	34.0	13.2	13.3
2005-302	1768M	1.4.2009	Purukeitto	ew dry	90.1	6	35	4.5	180	1000	42.6	0.04	42.6	27.1	39.1	13.3	15.2
2005-302	1771M	1.4.2009	Purukeitto	ew dry	90.1	6	35	4.5	180	1200	42.0	0.04	42.0	22	41.5	13.3	13.8
2005-302	1767M	1.4.2009	Purukeitto	lw dry	91.9	6	35	4.5	180	850	42.8	0.06	42.9	29	38.7	13.3	15.8
2005-302	1770M	1.4.2009	Purukeitto	lw dry	91.9	6	35	4.5	180	1050	41.8	0.04	41.8	24.3	40.7	13.3	14.0

Table 11. Pulp properties.

Sample		Number of tests	Ew 1749 m	Ref 1753 m	Lw 1754 m
Wet disintegration of chemical pulp	ISO 5263-1:2004				
Fibre distribution, FS-300	□				
- Arithmetic av. fibre length, mm			0.70	0.79	0.72
- Length weighted av. fibre length, mm			1.53	1.66	1.54
- Weight weighted av. fibre length, mm			2.13	2.26	2.19
- Length < 0,2 mm, %			5.36	4.17	4.46
- Fiber curl, %			7.5	7.7	7.1
- Kink index, 1/m			350	375	349
- Fiber width, µm			24.8	25.1	24.8
Grammage, g/m² *)	ISO 5270:1998		66.1	66.3	66.4
Bulking thickness, µm *)	ISO 5270:1998, ISO 534:1988	5	87.4	100	106
Standard deviation, µm			1.7	2	3
Apparent bulk-density, kg/m³ *)	ISO 5270:1998, ISO 534:1988	5	756	661	629
Standard deviation, kg/m³			14	13	15
Bulk, cm³/g *)	ISO 534:1988	5	1.32	1.51	1.59
Standard deviation, cm³/g			0.03	0.03	0.04
Tensile strength, kN/m *)	ISO 5270:1998, EN ISO 1924-2:1994	10	5.84	4.48	4.10
Standard deviation, kN/m			0.25	0.17	0.13
Tensile index, Nm/g *)	ISO 5270:1998, EN ISO 1924-2:1994	10	88.4	67.5	61.7
Standard deviation, Nm/g			3.8	2.6	1.9
Stretch, % *)	ISO 5270:1998, EN ISO 1924-2:1994	10	2.6	2.3	2.2
Standard deviation, %			0.2	0.2	0.1
Tensile energy absorption, J/m² *)	EN ISO 1924-2:1994	10	103	70.0	62.9
Standard deviation, J/m²			12	9.1	5.0
TEA index, J/g *)	EN ISO 1924-2:1994	10	1.57	1.06	0.948
Standard deviation, J/g			0.18	0.14	0.075
Tensile stiffness, kN/m *)	EN ISO 1924-2:1994	10	606	511	483
Standard deviation, kN/m			10	11	14
Tensile stiffness index, kNm/g *)	EN ISO 1924-2:1994	10	9.17	7.70	7.27
Standard deviation, kNm/g			0.16	0.17	0.21
Modulus of elasticity, N/mm² *)	EN ISO 1924-2:1994	10	6934	5095	4571
Standard deviation, N/mm²			120	111	129
Tearing strength, mN *)	ISO 5270:1998, ISO 1974:1990	5	583	833	881
Standard deviation, mN			14	24	40
Tear index, mNm²/g *)	ISO 5270:1998, ISO 1974:1990	5	8.82	12.6	13.3
Standard deviation, mNm²/g			0.21	0.4	0.6

Arrival date:25.5.2009
Date of tests: 26.5.2009/ask
Test conditions: 50% RH, 23°C
Approval: 26.5.2009 ELK

Compared at a constant H-factor, the lw-fraction was cooked to lower kappa number than ew-fraction (Fig.70). When air-dried raw materials were use, the difference was much smaller. The yield of lw-pulps was lower than that of ew-pulps (Fig. 70 left). Both fractions got smaller yield than the reference indicating that something was lost or some reactions have taken place during the fractionation and washing processes. This has also affected the higher brightness of the fraction-pulps (Fig.70 right).

The viscosities of the pulps at kappa level 25 were 920 (ref), 890 (ew) and 900 (lw) indicating that the yield loss is not because of excess dissolving of hemicelluloses (the viscosity of the fraction-pulps is not higher than that of the reference).

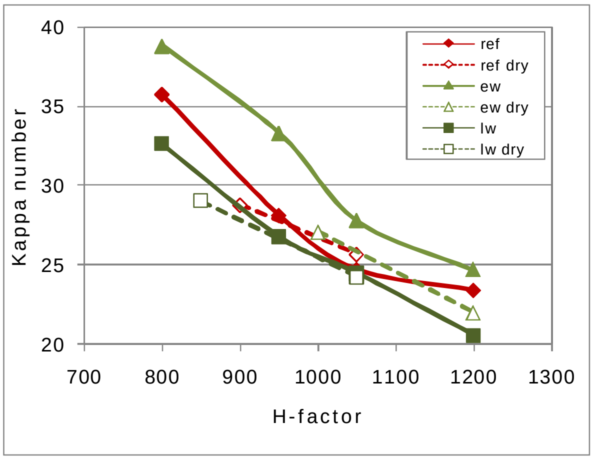

Figure 69. *Kappa number as a function of H-factor.*

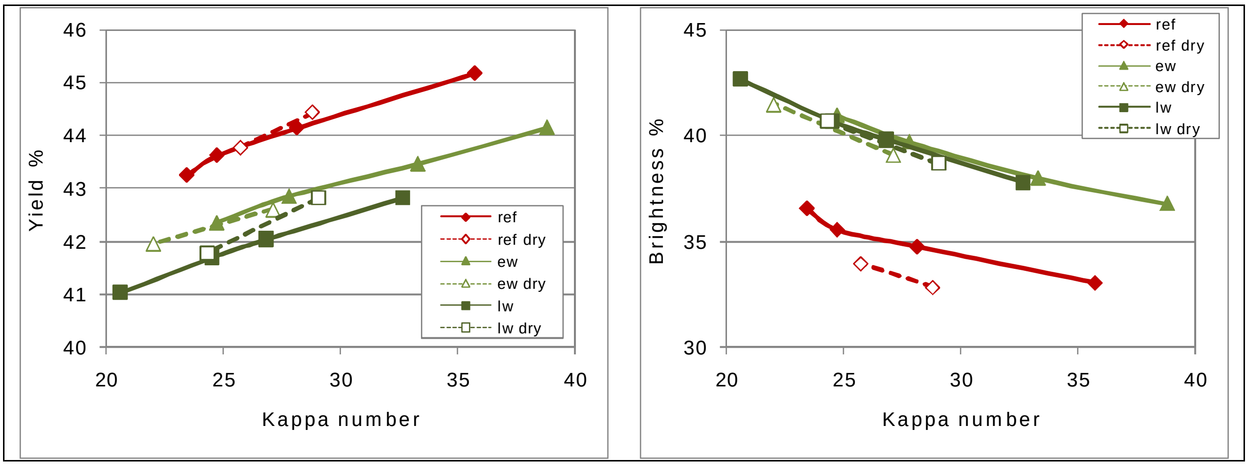

Figure 70. *Total yield and pulp brightness as a function of kappa number.*

Both fraction-pulps had 0.1 mm lower fibre length than the reference, Table 4. In general, severe fibre cutting has taken place already during the preparation of the pin chips (initial fibre length ca. 2.5 mm). The density of the laboratory sheets made of ew-pulp had much higher density, higher tensile and lower tear index than the lw-pulp. In general, the lw-pulp properties were closer to the reference pulp, but the ew-pulp was clearly different.

Table 12. *Fiber length and sheet properties of the cooked pulps.*

Sample	ref	ew	lw
Fiber length, lw, FS300, mm	1.66	1.53	1.54
Apparent bulk-density, kg/m³	661	756	629
Tensile index, Nm/g	67.5	88.4	61.7
Stretch, %	2.3	2.6	2.2
Tear index, mNm²/g	12.6	8.82	13.3