Saimaa University of Applied Sciences
Technology, Imatra
Degree Programme in Paper Technology

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LONGITUDINAL GRINDING OF ASPEN

Bachelor's Thesis 2011

ABSTRACT

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Longitudinal Grinding of Aspen,
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Technical Unit, Degree Programme in Paper Technology
Bachelor’s Thesis 2011
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The aim of this thesis work was to find out the paper properties obtained from longitudinal grinding of aspen. Mechanical Pulping, longitudinal grinding and short description of studied paper properties were introduced in the theoretical part.

The entire process included longitudinal grinding of aspen. There were five different points at which aspen were cut for longitudinal grinding. The points were at an angle of 0^0, 15^0,30^0,45^0 and 0^0 with reference of traditional grinding. For each point, pulp was prepared after longitudinal grinding and later extracted from pressure filtration. 10 test sheets from each point were made using recycled water and their properties were measured, analyzed and compared. Thickness, brightness and opacity, air permeability, bursting strength, tensile strength and tearing strength were measured. All the experiments were performed in the paper laboratory of Saimaa University of Applied Sciences.

Keywords: Mechanical Pulping, Longitudinal Grinding, Aspen, Pressure Filtration

Contents

1 INTRODUCTION 1
2 ASPEN 1
3 MECHANICAL PULPING 3
4 LONGITUDINAL GRINDING 4
5 SCREENING 5
6 PRESSURE FILTRATION 5
7 PAPER MAKING 6
8 PULP TESTS 7
8.1 Fiber Length Measurement 7
8.2 Freeness (CSF) 8
8.3 Water Retention Value (WRV) 8
9 PROPERTIES OF PAPER 9
9.1 Basis Weight, Thickness, Density and Bulk 9
9.2 Brightness and Opacity 9
9.3 Air Permeance 10
9.4 Bursting Strength 10
9.5 Tensile Strength 11
9.6 Tearing Strength 11
10 PROCEDURE 12
10.1 Longitudinal Grinding 12
10.2 Screening 14
10.3 Pressure Filtration 15
10.4 Pulp Tests 16
10.4.1 Fiber Length, Coarseness Measurement 16
10.4.2 Freeness (CSF) 17
10.4.3 Water Retention Value (WRV) 18
10.5 Preparation of Laboratory Sheets 19
10.6 Paper Properties 20
10.6.1 Thickness, Density and Bulk 20
10.6.2 Brightness and Opacity 21

10.6.3 Air Permeability 22
10.6.4 Bursting Strength 23
10.6.5 Tensile Strength 25
10.6.6 Tearing Strength 26
11 RESULTS AND DISCUSSIONS 27
11.1 Pulp Tests 27
11.1.1 Fiber Length, Coarseness 27
11.1.2 Freeness 28
11.1.3 Water Retention Value (WRV) 29
11.2 Paper Properties 31
11.2.1 Thickness, Density and Bulk 31
11.2.2 Brightness and Opacity 33
11.2.3 Air Permeability 34
11.2.4 Bursting Strength 35
11.2.5 Tensile Strength 36
11.2.6 Tearing Strength 37
12 CONCLUSION 38
FIGURES 40
TABLES 40
GRAPHS 40
REFERENCES 41

1 INTRODUCTION

A comparison of the paper properties obtained from longitudinal grinding of aspen at different angles was the main objective of this work. Shives were separated with somerville screen and pulp was collected with pressure filtration and papers of approximately same basis weight were made. This work includes a general background in Mechanical Pulping and aspen as a ground wood. Specifically, the work concentrates on longitudinal grinding of aspen.

A simple grinder was used for longitudinal grinding. A pressure filter was used for the extraction of pulp as a mass of cake. Recycled water was used to prepare the test sheets for all points. Throughout the procedure, fiber length of each angle i.e. 0^0, 15^0,30^0,45^0 and 0^0 with reference was measured by a fiber length measuring device FS-300. Freeness of the pulp at all points was also important to measure with the help of Canadian-Standard-Freeness (CSF-value) and was performed by a CSF-tester. Similarly, a laboratory centrifuge was used to measure the Water Retention Value (WRV) of the pulps. Finally papers were made from every points and their properties were measured and analyzed.

2 ASPEN

Aspen, as one of the hardwoods, due to sheer quantity alone, supports much of the logging industry. As noted by American Hardwood Export Council, [1], aspen does not split when nailed, it machines easily with a slightly fuzzy surface, and turns, bores, and sands well. It takes paint and stain well to produce a good finish although care is required where the surface is fuzzy. It has low to moderate shrinkage and good dimensional stability. Aspen is a true poplar, and therefore has similar characteristics and properties to cottonwood and European poplar.

Concerning to the European aspen, Kazimierz Lutomski *et al.* [2] says that; European aspen wood is characterized by high ability to absorb water solutions of salts in the transverse direction. Capillary absorption of European aspen wood along with grain is better for the outer zone. Storing of European aspen wood with bark in summer has the negative influence on its impregnation ability.

For the chemical composition of aspen, National Research Council (U.S) [3], reported that the protein content in aspen is less than 2 percent, and acid detergent fiber is usually in excess of 60 percent. Ash content in aspen is usually less than 1 percent, unless there is soil contamination, in which case ash content may range up to 10 percent and Kloson lignin content is usually between 16 and 22 percent. Western Excelsior Corporation [4] found on their research that the configuration of fiber dimension in aspen is cylindrical with closed ends with the shape of hog ring.

McGovern et al. with the help of data obtained from USDA Forest Service [5] reported that pulps of aspen made using chemical pretreatments of the chips gave considerably higher strength properties than those produced from the groundwood types. However, the light-scattering coefficients and fiberizing energies were reduced from chemically pretreated pulps and the biomechanical pulp showed lignin loss with improved handsheet strength properties. Waleed Wafa Al-Dajani *et al.* [6] reported that the aspen chips prior to kraft pulp obtained from pre extracted chips have slightly higher cellulose/hemicellulose ratio, and demonstrate a small decrease in tensile index leaving behind improved brightness and shive content.

3 MECHANICAL PULPING

Pulping Processes are very broad technologies with respective process modeling. Simply after the initial stages; debarking or deicing, the process undergoes several stages of converting wood or lignocellulosic nonwood material to separated pulp fibers for papermaking. The aim of mechanical pulping of wood is to produce fiber material with ideal properties for a specific paper making process. Basically spruce, pine and hardwood species like aspen are today of increasing interest for mechanical pulp.

Industrial pulping involves the large-scale liberation of fibers from lignocellulosic plant material, by either mechanical or chemical process. Chemical pulping relies mainly on chemical reactants and heat energy to soften and dissolve lignin in the plant material, partially followed by mechanical refining to separate fibers. Mechanical pulping involves the pretreatment of wood with steam and sometimes also with aqueous sulfite solution prior to the separation into fibrous material by abrasive refining and grinding. Depending on its end-use, the material from such process – unbleached pulp - may be further treated by screening washing bleaching and purification (removal of low molecular-weight hemicelluloses) operations. (Paper Industry Technical Association [7]).

Mechanical pulp is made by grinding logs or refining chips. Mechanical pulp contains all the natural tree substances. Some manufacturing processes are simpler than those used to produce chemical pulp partly because the recovery system for chemicals is not necessary. Using higher pressure, temperatures, or chemical treatment often enhances the pulping methods. Mechanical pulping is the process by which fibers are produced through mechanical methods. From the Handbook of Mechanical Pulping [8], mechanical pulps typically have high yield, normally 97% - 98% with Norway spruce, compared with chemical pulp yield of 45%-50%. So, higher amount of papers can be made from a certain quantity of wood by mechanical pulping. It also illustrates some major drawbacks of mechanical pulping is that it takes higher consumption of electric energy and the bonding capacity of mechanical pulp fibers is lower than that of chemical pulp fibers, which results in lower overall strength properties for mechanical pulps.

4 LONGITUDINAL GRINDING

This research draws the attention towards the Mechanical Pulping using a simple grinder working at an atmospheric pressure. The pulp stone inside the grinder is so-called ceramic stone. All pulp stone manufacturers have their own detailed constructions which are based on the same basic structure – ceramic segents attached to a steel-reinforced concrete core. The log of aspen was cut at different angels for the longitudinal grinding as shown in figure 1.

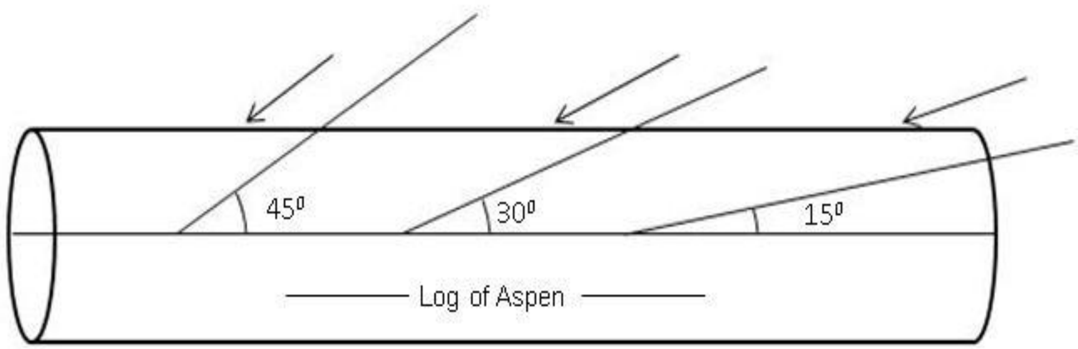


Figure 1. Longitudinal Grinding

Longitudinal grinding refers to the way wood chips are feed into the grinder. The chips of different angels viz. 0^0,15^0,30^0 and 45^0 were introduced to the grinder longitudinally. As the pulp stone rotates anti-clockwise inside the grinder, the wood chips were feed into the grinder so that they are against the pulp stone. This research holds the properties of different papers made from the pulp of Aspen from longitudinal grinding.

5 SCREENING

Although the properties of the ground wood are quite highly developed in the grinding process, the pulp is as such by no means finished and ready to be supplied to a paper or board machine. After grinding, the ground wood still contains shives and coarse fiber bundles, which have to be reworked according to the requirements of each paper or board grade produced. The function of screening and reject handling is to homogenize the ground wood and to reduce or remove contained impurities. The major purpose of screening is to separate contaminants such as shives and other unwanted particles from the pulp fibers for subsequent examination and quantification. (Screening of pulp [9])

6 PRESSURE FILTRATION

Pressure Filtration is simply the separation of water from the pulp just after screening. Both fibers and fines are acquired in a mass of a cake from pressure filtration. Pressure filters are the semi-continuous type machine that enter a wash and cake discharge mode at the end of the filtration cycle. The filtration cycle takes hours depending on the amount of pulp that is to be filtrated. From the Engineering aspects in solid-liquid separation [10], it is suggested, pressure filtration can replace other separation methods such as thickening for the mechanical pulping. The pressure filtration not only increases the amount of yield but also preserves fines going to the sewer.

Since the operation is in batches, that are usually fed from and discharged to a continuous process, a surge tank is required upstream the filter and batch collection of cake downstream the filter [11.] The collection of filtrate depends on the operating mode of the filter which can be constant flow rate, constant pressure or both with pressure rising and flow rate reducing as for a centrifugal pump. The filtration rate is influenced, in broad terms, by the properties of the slurry. The trend is that the rate goes up with increased pressure, coarser particles, particle distribution with high uniformity, non-slimy or non-gelatinous solids, non-compressible cakes, lower liquid viscosity and higher temperatures.

7 PAPER MAKING

The characterization of the pulp for the observation of the manufacturing process of pulp and for the estimation of the pulp applicability to some product is usually made by preparing laboratory sheets from the pulp. Laboratory sheets are meant to simulate the paper machine process. Although there are clear differences in the forming processes of a sheet former and a paper machine wire section, and thus the properties of the laboratory sheets differs from the properties of the sheet made on paper machine.

Paper making with recycled water has an influence on the basis weight of the papers made from it. As the water is used, collected and reused in papermaking process, the concentration of suspended solids or fines may increase. Fines play a very important role in the papermaking process and paper properties. As reported by Hongbin Liu *et al.* [12], high-yield pulp contains a large amount of higher specific surface area fines and more dissolved and colloidal substances (DCS) than do the fibers. Furthermore, it says that the effect of amount of fines in the pulp can be detrimental to the paper product of process of papermaking. Taking this into account, the fines that is actually making differences in the basis weight of the paper is recycled each time until it reaches a constant level in the recycle pulp.

8 PULP TESTS

8.1 Fiber Length Measurement

Length of fibers (arithmetic average, weighted average etc.) is one of the most important parameters of pulp. Pulp strength is directly proportional to fiber length and dictates its final use. M Graca *et al.* [11] suggests that a long fiber pulp is good to blend with short fiber pulp to optimize on fiber cost, strength and formation of paper. Softwood with pulps in general has longer fiber compared to hard wood pulp. Pulp made from woods grown in cold climate in general has longer fiber compared to wood grown in warmer climates. The reference also says that the chemical pulps in general have higher fiber length compared to semi chemical pulp and mechanical pulp, when made from same wood. More fibers get damaged/shorten by mechanical action than chemical action.

As clarified by the Handbook of Pulp 2006 [13], the predominant use of the fiber material is the manufacture of paper, where it is re-assembled as a structured network from an aqueous solution. Fiber morphology such as fiber length and fiber geometry has a decisive influence on the papermaking process. A high fiber wall thickness to fiber diameter ratio means that the fibers will be strong, but that they may not be able to bond as effectively with each other in the sheet-forming process. Another property which is important to fiber strength is the spiral angle of the longitudinal cellulose micelle chains which constitute the bulk of the fiber walls. Moreover, certain chemical properties of the fibers and the matrix material in which they are embedded must also be taken into account.

8.2 Freeness (CSF)

The ‘Canadian Standard Freeness’, CSF value is a comparative measure to drainage time of pulp. It is designed to provide a measure of the rate at which a dilute suspension of pulp may be dewatered. From the mini encyclopedia of paper making wet end chemistry [14], the drainability is related to the surface conditions and swelling of the fibers, and constitutes a useful index of the amount of mechanical treatment to which the pulp has been subjected. Indeed, the faster slowing of draining due to fiber accumulation on the screen plate gives a smaller CSF number. CSF is the amount of water passing through the side orifice of the tester. It depends on the conditions of measurement, particularly the geometric characteristics of the instrument.

8.3 Water Retention Value (WRV)

The water retention value (WRV) test provides an indication of fibers' ability to take up water and swell. According to Scandinavian pulp, paper and board testing committee 2000 [15], WRV is an empirical measure of the capacity of a test pad of fibers to hold water. The WRV value increases with increasing beating because of internal fibrillation, a widening of the small internal pores and delaminations, which has been called ‘swelling’ and which occurs concurrently with the development of external fibrils, which also serve to hold additional water.

To define, Water Retention Value is the ratio of the mass (weight) of water retained after centrifugation under specified conditions by a wet pulp sample to the oven dry mass (weight) of the same pulp sample.

9 PROPERTIES OF PAPER

The properties of paper identify the quality of the pulp and summarize the theme of this research. Some basic paper properties were studied.

9.1 Basis Weight, Thickness, Density and Bulk

Basis weight or grammage of paper is the weight of the one square meter of paper (g/m^2). Its SI- unit is kg/m^2.

Thickness of paper is measured by applying pressure between two parallel plates and is expressed in µm. If the measurement is made from a single sheet, it is called single sheet thickness. Bulking thickness is the average thickness of one sheet calculated from the thickness of a pad of sheets. Because of the variations and compressibility of paper and the uneven character of its surface, the bulking thickness value is usually lower than the single sheet thickness value.

Density of the paper is the mass per unit volume calculated as the ratio between basis weight and thickness of the material in kg/m^3. The density can be reported either as the apparent bulk density based on bulking thickness or as apparent density based on the single sheet thickness.

Bulk is the inverse number of the density expressed as cm^3/g.

9.2 Brightness and Opacity

Optical properties are measured from the air conditioned papers in the air conditioned room. It can be measured by using Lorentzen & Wettre Elrepho-tester. It is the specularly and diffusely reflected light component measurement against a known standard. [16] Brightness is important for magazine advertisements printing. The level of brightness desired is very dependent on the end use of the paper. Brightness and smoothness are different properties and are not dependent on each other.

Opacity is the measure of how much light is kept away from passing through a sheet. A perfectly opaque paper is the one that is absolutely impervious to the passage of all visible light. It is the ratio of diffused reflectance and the reflectance of single sheet backed by a black body. Opacity is important in Printing Papers, Book Papers, etc. The opacity of paper is influenced by thickness, amount and kind of filler, degree of bleaching and coating etc. (Booklet Printing, LLC [16]).

9.3 Air Permeance

Air permeance of paper simply measures the air permeability that is normally measured using air leakage instruments of different types. This is done by using the Bendtsen tester and it is actually the volume flow of the air that pressure difference provides through $10cm^2$ area. The measurements can be done from the whole trimmed air conditioned sheets. [17]

9.4 Bursting Strength

Bursting strength of paper identifies the resistivity of paper on applying pressure. Bursting strength tells how much pressure paper can tolerate before rupture. It is usually important for bag papers. Bursting strength is measured as the maximum hydrostatic pressure required rupturing the sample by constantly increasing the applied pressure. [17]

9.5 Tensile Strength

Tensile strength is the highest loading rate a paper or board sample sheet can withstand without breaking, when being stretched in the surface direction. Paper and board are required to have a sufficient general level of strength, which can be indicated with the paper tensile strength. For example, printing papers must be strong enough not to break in printing presses.

The durability of corrugated board when under strain can be predicted by testing the machine direction tensile strength and breaking strain of board components. The same also applies to, for example, packaging papers, which must be strong enough to protect the packaged goods. The tensile strength can be measured with a horizontal tensile testing machine using constant rate of elongation. Preferable unit is kN/m. [17]

9.6 Tearing Strength

The tearing strength of the paper is the mean force required to continue the tearing of paper from an initial cut in a single sheet or a pad of sheets. Tearing strength simulates the situation when there is some defect in the border of the paper web, e.g. hole, tear or stick. Then the strength of the continuous tear is smaller than it is in the whole paper web. Tear strength is indicated by the force required to effect a specific tear size.

The cross-directional tear strength of paper is used in estimating its capacity for fault tolerance. Printing press web breaks are usually caused by dirt, holes, stress peaks in areas around edge faults, etc. which result in a cross-directional tear. Therefore, the paper should be able to resist the tearing caused by such stress peaks. Tearing strength of paper sheets could be measured by the help of Elmendorf-type tester. [17]

10 PROCEDURE

The entire process of longitudinal grinding of aspen developed a sequential steps starting from wood cutting and pulping techniques to paper making. Pulp tests and paper making processes were carried out sideways. At first, log of aspen provided at the laboratory was cut as shown in fig 1. p 4 to acquire the pieces of aspen with 0^0,15^0,30^0 and 45^0 inclination. The fibers inside the wood at all points were inclined to the same angles accordingly. For each pieces of all points, the logs of wood were cut into 12 small cubes. The cubes were furnished to give a final size of 4.2mm×4.2mm measurements so that they could be perfectly fitted to feed into the laboratory grinder for the longitudinal grinding of aspen.

10.1 Longitudinal Grinding

A simple laboratory scale stone grinder was used for the longitudinal grinding of aspen. The grinder works in an atmospheric pressure. It has a 32A type of pulp stone which revolves anti-clockwise inside the machines shown in figure 2. From the Handbook of mechanical pulp [6], the number 32 refers to the size of the grit whereas letter A shows the indication of aluminium oxide (ALUNDUM) as the abrasive type. The book refers that the grit size is chosen according to the quality requirements set by the paper grade and the wood species used. The finer the pulp required, the finer the grindstone.

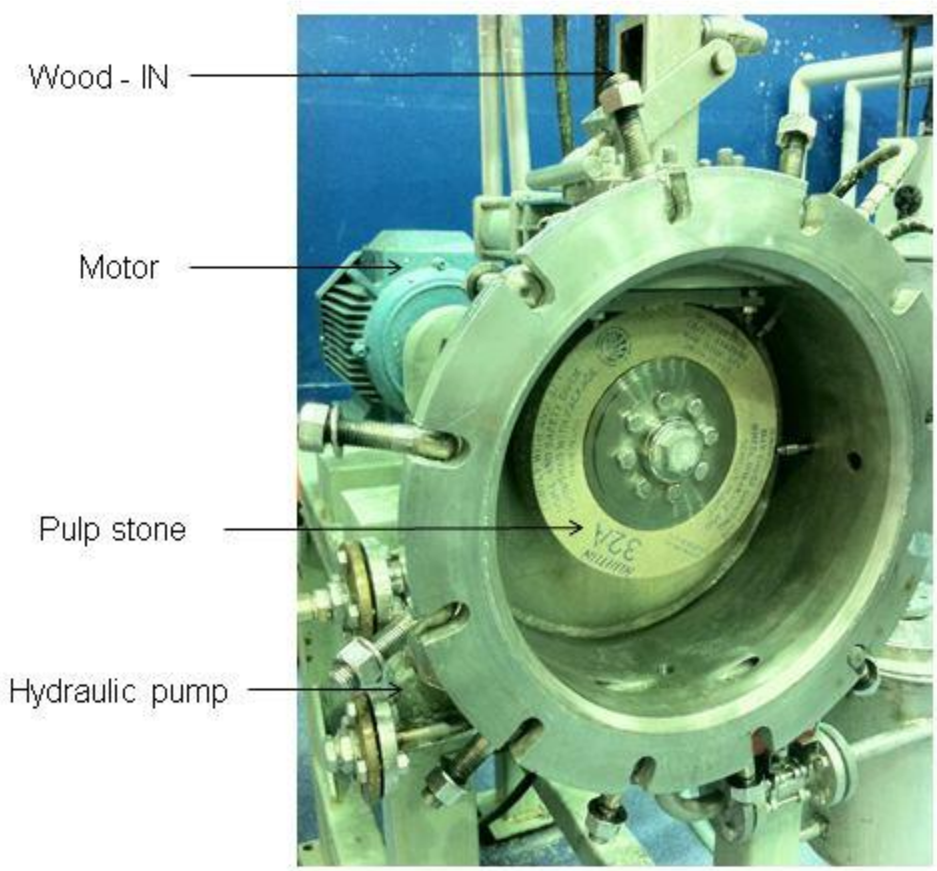


Figure 2. Laboratory Grinder

The machine was run by operating the hydraulic pump. A continuous water flow throughout the machine was allowed whilst it was working. When the grinder reaches a constant speed of 1500 rpm, the cubes of aspen were fed into the grinder longitudinally as shown in fig 3. Apart the traditional grinding, wood cubes were fed into the grinder longitudinally where the fibers are vertical to the position. A piston attached to the grinder was used to push the wood cubes inside the grinder. The wood cubes were fed longitudinally so that they were crushed against the direction the pulp stone was rotating.

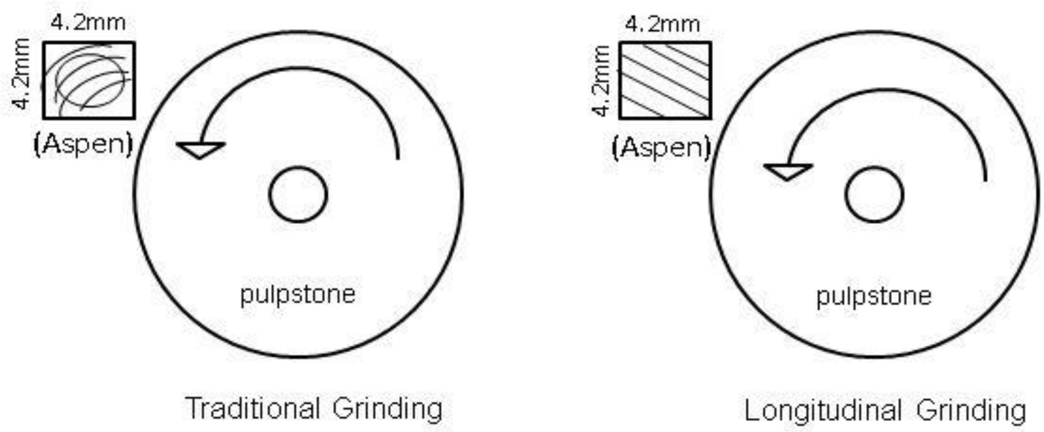


Figure 3. Traditional Grinding and Longitudinal Grinding

The cubes of aspen were pressed against the rotating, properly conditioned or sharpened pulpstone, while the stone surface was simultaneously cleaned and cooled by using shower waters. Finally, the pulp was collected in the receiver. At frequent times, a pressurized air was introduced inside the grinder so that the mass of pulp did not stick inside the machine. The process was repeated for all points including the one with the traditional grinding. The traditional grinding was taken for a reference.

10.2 Screening

Straight after the longitudinal grinding, the pulp was taken for screening. Somerville screen present in the laboratory was used to remove wood cubes and shives from the pulp. A continuous flow of water was used throughout the process. The pulp was then collected in big buckets so that both fines and fibers were collected which was then taken for pressure filtration.

10.3 Pressure Filtration

For the separation of water from the pulp, a pressure filtration machine was used which was manufactured by Larox as shown in figure 4. Compressed pressure was introduced to the machine by a pipe and pulp after screening was kept inside the tank of the machine. A pulp receiving filtering cloth was placed in between two parallel plates of the machine. The cloth consists of numerous small pores that do not let the fines and fibers pass to the sewer. The plates were then compressed together at an elevated pressure.

Figure 4. Pressure Filtration

The pressure filtration machine was run to collect the pulp in the cloth as a form of a cake. The water coming out of the machine was recycled until it contain no fines and fibers. Clean water was let pass to the sewer. After a certain time, the pressure was released from the machine. Finally, the pure pulp containing both fines and fibers was collected in the cloth while the water was passed to the sewer. The main aim of using pressure filtration was to prevent the loss of both fines and fibers from the pulp.

10.4 Pulp Tests

All the pulps were prepared at each point after longitudinal grinding and pressure filtration. It was important to test each pulp with their fiber length, freeness and water retention value. For all the tests, it was an initiation to measure the dry content of the pulps.

The dry content was measured by the moisture analyzer as shown in figure 5. A small amount of pulp was kept in the machine and it gave exact amount of dry content in percentage (%) automatically after certain interval of time. Amount of required wet pulp can be known from following equation.

Figure 5. Moisture Analyzer

$$Wet\_pulp = \frac{mass(m)}{Dry\_content} \times 100 \tag{1}$$

10.4.1 Fiber Length, Coarseness Measurement

Fiber Length of each pulp was measured by Kajaani FS-300. It is a modern fiber analyzer for the routine measurement of various fiber properties in the laboratory. The machine was operated by a computer program, 'FS-Server'. The machine did not only measure the number of fines and fibers with their length but also measured the coarseness and their weights.

Preparing the sample for the fiber measurement, a 500mg of dry pulp was mixed into 5 liters of water and was swirled with a glass rod. The mixture was mixed properly so that there were not too long fibers. Small amount from the mixture was taken as a sample for the fiber measurement. The machine was washed before and after each measurement so as to confirm the absence of impurities.

10.4.2 Freeness (CSF)

The Canadian-Standard-Freeness (CSF- value) was measured by filtrating 1L of stock freely through the screen plate of the tester. It is performed by the CSF-tester in the laboratory as shown in figure 6. Faster slowing of draining due to fiber matter accumulation on the screen plate gives a smaller CSF number. CSF is the amount of water passing through the side orifice of the tester.

Figure 6. CSF Tester

Every time the freeness of each pulp was measured, first the drainage chamber and the funnel were rinsed carefully with water at a temperature of 20^0C so the temperature of the device is even. A stock sample of 4g of wet pulp and 1l of water was prepared. The drainage chamber was set on its place and the bottom lid lever was closed opening the lid lever and the air valve. Two vessels of capacity 1l was set into their positions, one under the side orifice and another under the bottom orifice. Then, the sample was mixed carefully and poured into the drainage chamber gently but as rapidly as possible. The lid lever and air-cock were closed and the bottom lid was open. After 5 seconds from the time the addition of the stock is completed, the air cock was fully opened at once. When the side discharged had ceased, the volume discharged from the side orifice was recorded in millimeters to the maximum accuracy possible.

10.4.3 Water Retention Value (WRV)

For each pulp, four different samples each containing 1g of dry pulp was prepared. Each 1g sample was made homogeneous mixture with small amount of water. The samples were put inside special cups especially used in the laboratory centrifuge machine as shown in figure 7 to measure the water retention value.

Figure 7. Laboratory Centrifuge

All four samples were filtrated by suction using Buchner's funnel. After all the water had been soaked up, the cups were put into the centrifuge. With 4300rpm of the centrifugal acceleration, the machine was run for 10 minutes exactly. Then, the mass of each sample after centrifuge was noted and the same samples were kept in oven for a day. The weights of oven dry samples were finally recorded and the water retention value was as follows:

$$WRV = \left(\frac{m_1}{m_2} - 1 \right) \times 100\% \qquad (2)$$

Where, m_1 is the mass of the centrifuged wet pulp sample, in grams;
m_2 is the mass of the dry test pulp sample, in grams.

10.5 Preparation of Laboratory Sheets

The laboratory sheets were prepared in the laboratory by using recycled water. The fines present in the pulp are also recycled along with the recycled water giving a constant basis weight to the paper after a complete recycling of water. Turning on the water and air valve, the paper making process was started. The paper making process undergoes filling of water, addition of pulp stock sample, whirling, fall through, suck off, drainage and drying. Every 10 minutes, a paper was prepared and was carefully taken out from the dryer. The paper was dried in oven and its basis weight was checked. The basis weight of the paper was targeted to be 80g/m^2. As the radius of the machine was 0.1m, the equivalent sheet mass as targeted was calculated as follows;

$$\frac{80\, {}^{g}\!/\!{}_{m^2}}{\pi \times 0.1^2} = 2.5gm.$$

10-sheets weighing nearly around 2.5g each from each point of pulp viz. 0^0, 15^0,30^0,45^0 and 0^0 with reference were made ready to test for the paper properties.

10.6 Paper Properties

The papers obtained from every point were measured one by one for their properties that were interesting for this work. All the properties have their own significance regardless of the aim to characterize the longitudinal grinding of aspen.

10.6.1 Thickness, Density and Bulk

A micrometer was used to measure the thickness of the papers as shown in figure 8. All the measurements were done on a single sheet but twice on different positions and a mean value was reported as bulking thickness. The measurements were started by pushing the button located at right hand side of the micrometer. As the probe rose up, the sample paper was placed in between the champs. On releasing the button, the probe lands to the surface of paper giving the exact thickness of the sample paper in mm. The results were reported in μm.

Figure 8. Micrometer

The density of the paper was calculated as the ratio between basis weight and thickness of the material in kg/m^3. And, bulk was calculated just making inverse number of the density of paper and it is expressed as cm^3/g.

$$Density, d = \frac{basis\_weight(kg/m^2)}{m} = \frac{kg}{m^3} \quad (3)$$

$$bulk, \rho = \frac{1}{d} = \frac{cm^3}{g} \quad (4)$$

10.6.2 Brightness and Opacity

Brightness and Opacity of papers were measured by Elrepho-tester as shown in figure 9 which is manufactured by Lorentzen and Wettre. Elrepho automatically measures according to the conditions specified to the computer. It is easy to operate due to measurement table and optimized measurement program for routing testing. Just one calibration was enough for all conditions.

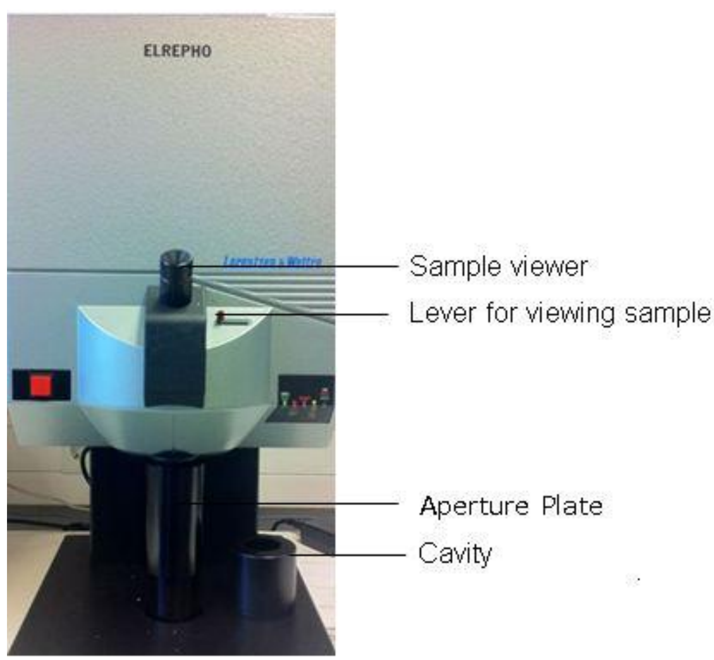


Figure 9. Elrepho Tester

With the help of the sample viewer, the same area of the sample viewed by the lens could be seen. The equipment measures the light intensity passing through the paper. All 10 test sheets were compiled and were placed over the pad or aperture plate. Once the sample was properly positioned, the lever was returned to the far-left position. First ten measurements were done over the pad and second ten measurements were done over the cavity by placing only one test sheet at a time. Finally, the machine gave the result of brightness and opacity in a mean value of all the test sheets measured.

10.6.3 Air Permeability

Air permeability of all paper sheets was measured one by one by using Bendtsen tester as shown in figure 10. Initially, the air valve was opened and the equipment was turned on. Permeability was selected to measure in the unit in ml/min at a pressure difference of 1.47kPa through $10cm^2$ area.

Figure 10. Bendtsen Tester

Each test sample was placed in between the clamps of the air permeability measuring head. The measuring head was closed by pushing the handle down position and holding it in that position. The measurement was started. After the stable pressure reading, the machine gave the result of air permeance. The measuring head was then opened and a new sample was taken into account in the similar way. After the last sample for each 10 test sheets, the measurement was stopped and the average result along with standard deviation and the highest and lowest measurement were noted. The air permeability was finally calculated as follows;

$$Air\_permeability = \frac{u}{A + \Delta p} \qquad (5)$$

Where,

u is volume flow of the air
A is measurement area
Δp is pressure difference between both sides

10.6.4 Bursting Strength

The bursting strength of the papers was measured by using a machine so as called burst-o-matic as shown in figure 11 which is also manufactured by Lorentzen and Wettre.

Figure 11. Burst-O-.Matic

First, the air valve was opened at least half an hour before the machine is switched on. The machine measures the pressure exerted in the unit of kPa. Before any measurement was done, the machine was checked if the internal pressure was at 1606kPa or not. It was set at this position by maintaining zero position when the switch was turned to ‘memory off’ position. After maintain zero position, the sample test sheet was placed in the plate of the machine and the bursting strength of the test sheet was recorded. The process was repeated twice for the same sheet of paper and a mean value was reported.

10.6.5 Tensile Strength

The tensile strength of the papers was measured by the tensile strength tester as shown in figure 12. First, a part of each test sheets was cut having width of 12mm. In the tensile strength tester, the test piece each of 12mm in width was stretched to the point where rupture occurred. The maximum tensile force the test piece can withstand before it breaks and the corresponding elongation of the strip were measured and recorded by the tester. For each measurement, the measuring piston was brought back to its initial position so that new measurement begins from the zero position.

Figure 12. Tensile Strength Tester

10.6.6 Tearing Strength

The tearing strength of the papers was measured by the Elmendorf-type tester as shown in figure 13. It is a physical pendulum that applied the tearing force by moving pendulum in a plane perpendicular to the initial plane of the test piece. The work done in tearing the test piece was measured by the loss in potential energy of the pendulum.

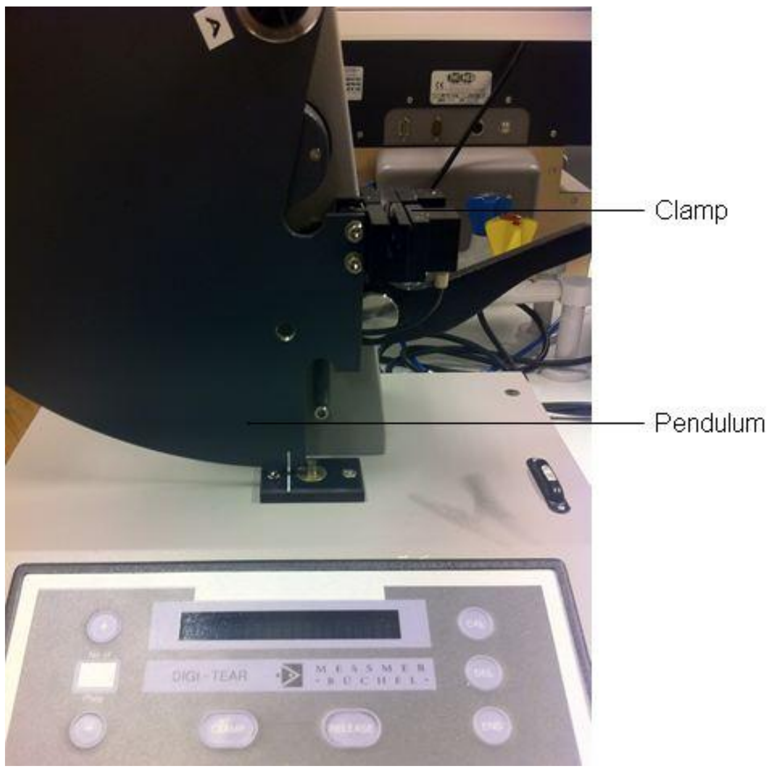


Figure 13. Elmendorf-type Tester

For the measurements, first the sample paper was cut into three different pieces each measuring 62mm long ×50mm wide. The number of the test pieces is adjusted as 3 as the number of layers of the cut pieces into the tester. All the test pieces were piled together and positioned in between the clamps so that the shorter side was towards the clamps. After pushing the clamp button, initial tearing was done by pushing the handle of the tester of the knife to the bottom. Measurement was done by releasing the pendulum simply pushing the release-button. The measurements were recorded in mN.

11 RESULTS AND DISCUSSIONS

All the pulps acquired from the longitudinal grinding and the one with traditional grinding were tested for the pulp properties. Ten different sheets were made from each of the pulps. All 10 sheets were measured and analyzed for their paper properties. The results for the pulp tests and the paper properties are tabulated and graphically represented in the following.

11.1 Pulp Tests

The result of the pulp tests are as follows:

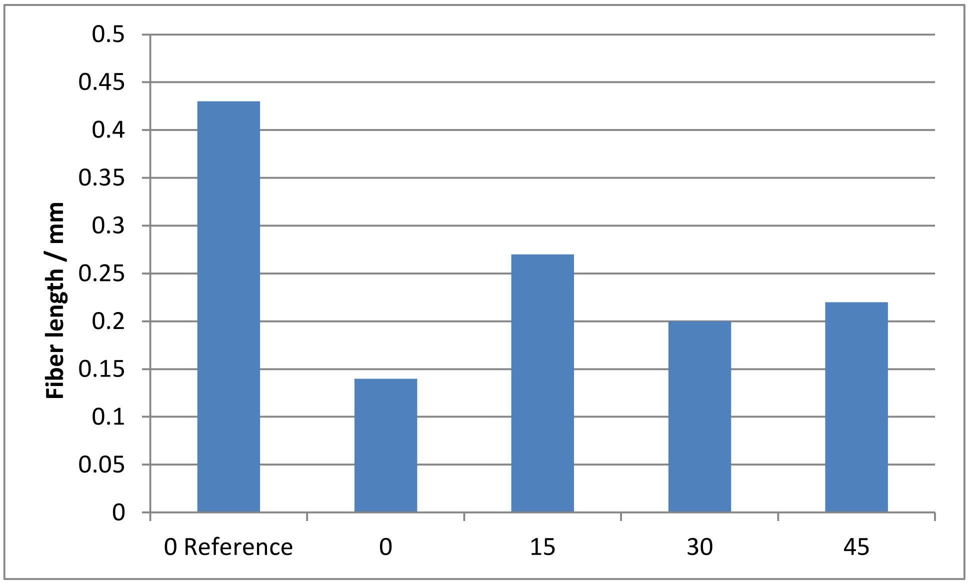
11.1.1 Fiber Length, Coarseness

The results acquired from FS-300 are attached in Appendix 1. The variations in the fiber length from the tables in appendix 1 were tabulated as following table.

Table 1. Fiber Length measurement

Point	Fiber Length /mm	Length Weighted /mg
0 Reference	0.43	2
0	0.14	5
15	0.27	3
30	0.2	2
45	0.22	2

The fiber length of the pulp seems to be at an average length of 0.2 mm for the longitudinal grinding except to that for the 0 degree and the one with the traditional grinding.



Graph 1 Fiber Length Measurement

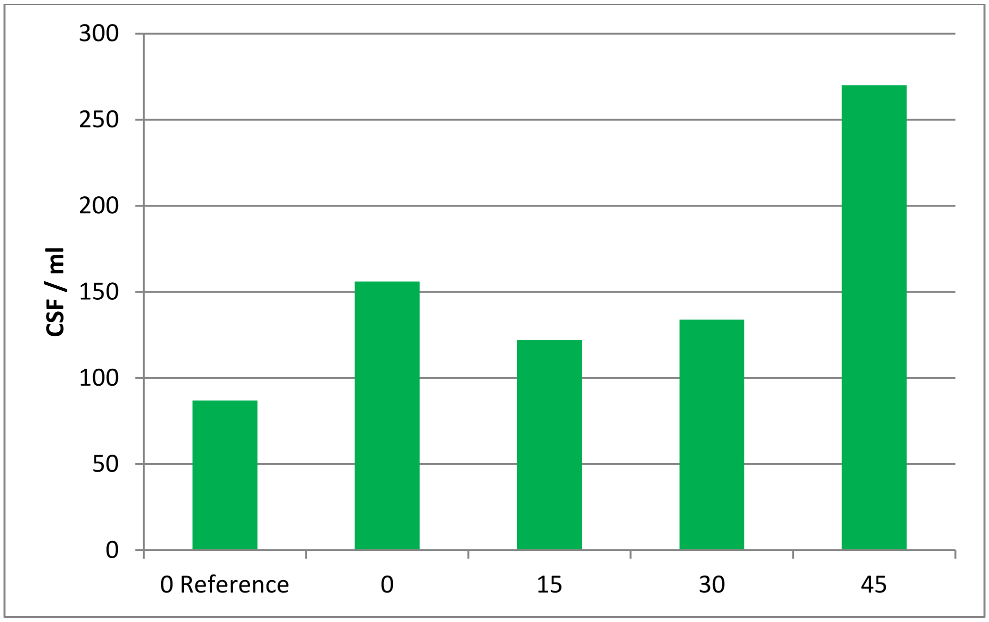
Fiber lengths are shorter for the longitudinal grinding than to the traditional grinding. Apart for the reference or traditional grinding, the coarseness is higher than the fiber length in the longitudinal grinding. And the coarseness for the 0 degree in longitudinal grinding was at a very higher range. However, fiber lengths for the pulp of longitudinal grinding were almost of the same length.

11.1.2 Freeness

From the 1000ml of stock sample, the freeness values of the suspended water from the pulp in the CSF tester are as follows;

Table 2. Freeness Result

Point	CSF/ml
0 Reference	60
0	120
15	90
30	100
45	220



Graph 2. Freeness Measurement

The measuring cylinder measured the volume with an error less than 1,0ml. The freeness for 45^0 pulp of longitudinal grinding is a much more compared to other pulp. There must be some discrepancy in the result. Even on repeating the test, it did not support the expected result. However, in other cases for longitudinal grinding, the freeness accepts to be at a range of 100ml whereas the freeness for traditional grinding is quite low.

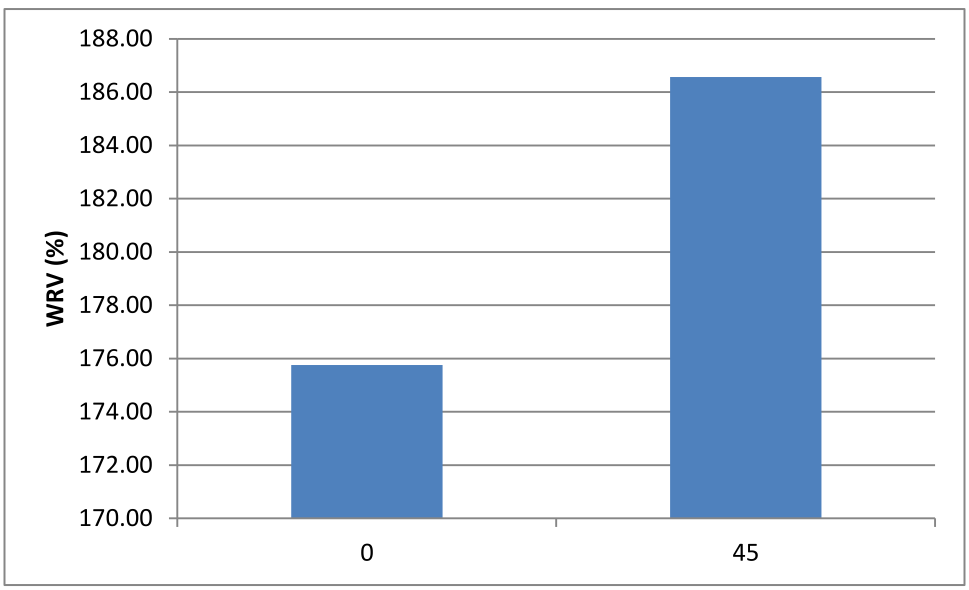
11.1.3 Water Retention Value (WRV)

Considering the mass of centrifuged wet pulp be m_1 and that of oven dry pulp be m_2, then the water retention value was calculated with the help of equation (2), p 19. The results as expected did not came with the pulps of traditional grinding, 15^0 and 30^0. The experiment errors could be drawn because of excess water during centrifuge or insufficient suction of water during suction filtration. The WRV for 0^0 and 45^0 are tabulated below:

Table 2. Water Retention Value Calculations

Sample	centrifuged wt./mg	dry wet/mg	WRV	**WRV (%)**
1.00	3.42	1.22	1.80	
2.00	2.88	1.02	1.82	
3.00	3.45	1.22	1.83	
4.00	3.40	1.32	1.58	
0 degree			**7.03**	**175.76**
1.00	2.50	0.91	1.75	
2.00	2.65	0.94	1.82	
3.00	3.13	0.98	2.19	
4.00	2.54	0.94	1.70	
45 degree			**7.46**	**186.56**

Plotting the graph for the mean of water retention values with respect to the point of the experimental grindings,



Graph 3 Water Retention Value

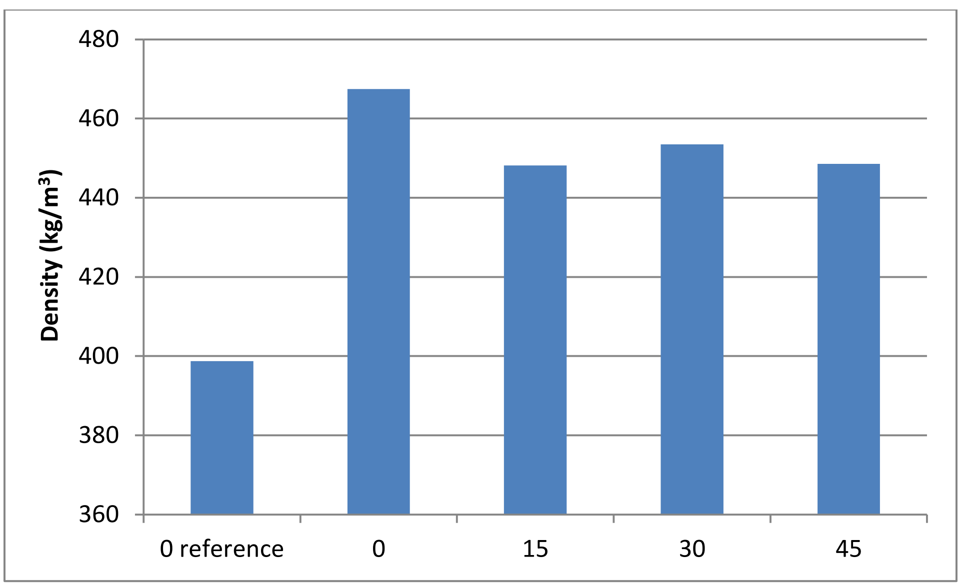
The graph clearly shows that the water retention values are near 200%. Infact, the WRV for 450 is rather higher than that of the 00. There has been a progression to the water retention values to the higher angle of longitudinal grinding.

11.2 Paper Properties

Each set of ten test sheets from every point of pulp was tested to characterize the properties of paper and accordingly the pulps and effect of longitudinal grinding.

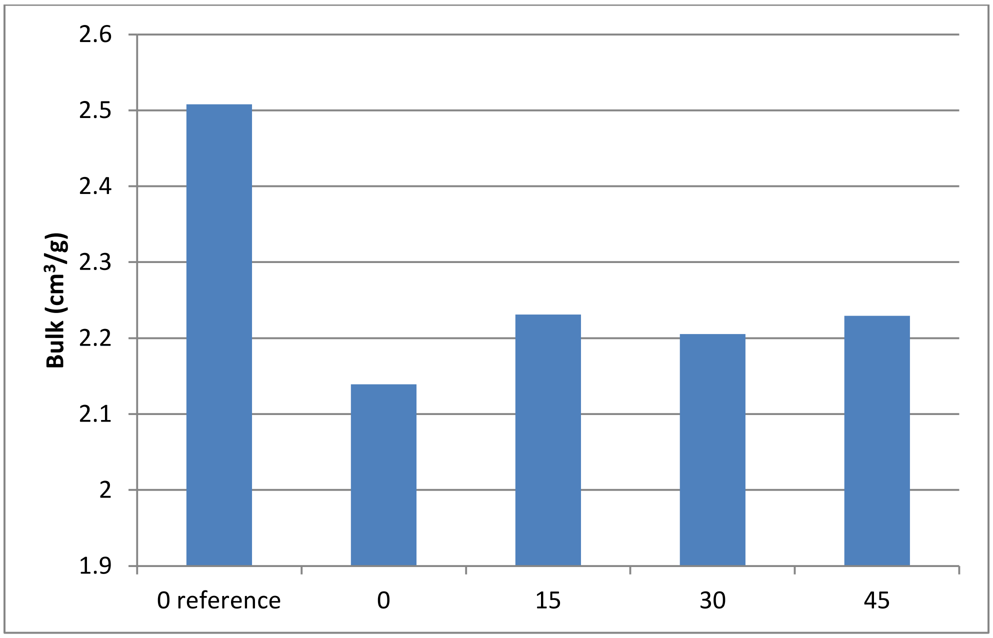
11.2.1 Thickness, Density and Bulk

The thickness of each paper was measured twice and the mean value was used. Density and Bulk are calculated accordingly with the help of the thickness measurements and the basis weight of the paper. Density and Bulk is calculated from eqn (3) and (4) respectively, p 21. The calculated values are reported as following:



Graph 4 Density Variations

The graph clearly shows that the density of the papers is increasing as the longitudinal grinding proceeds. Especially, the paper made from the pulp of 45 degree has the highest density. Then, the bulk of the paper should result as reciprocal to the density.

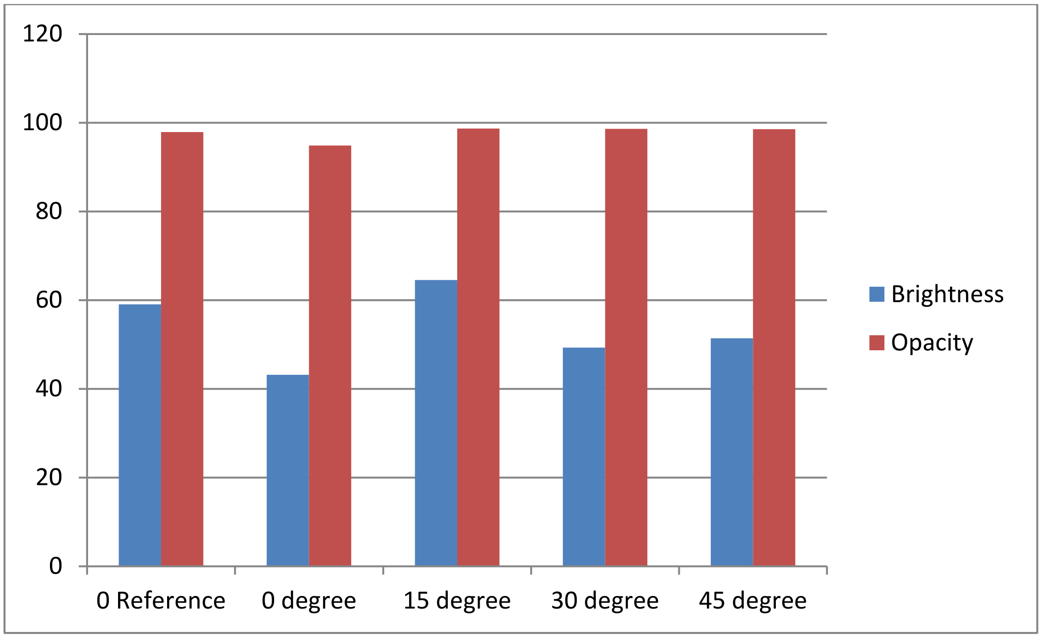


Graph 5 Variations in the bulk

The bulk of the papers of traditional grinding is much higher than the other point of papers. Indeed, the longitudinal grinding for 0^0, 15^0 and 30^0 has papers of almost the same range of bulk.

11.2.2 Brightness and Opacity

Each 10 test sheets were compiled to get the result of brightness and opacity. Thanks to the Elrepho type tester. Ten different measurements were done with over pad and another ten measurements were done over the cavity. The mean results were reported by the machine in percentage (%) values- The results are as follows;

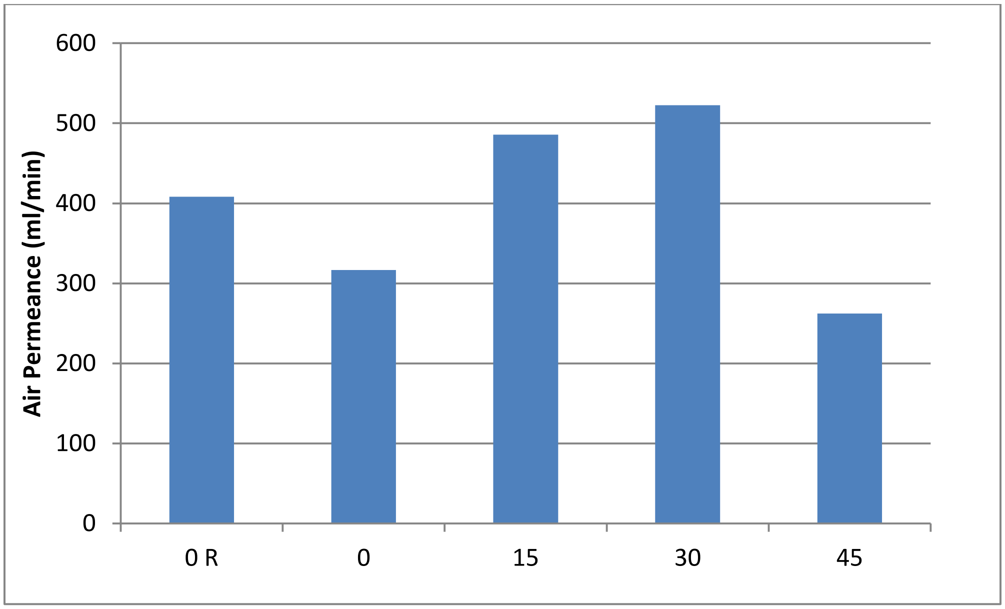


Graph 6 Brightness and Opacity

The graph shows the same level of opacity for all grades of papers. But the brightness of the paper has some variations, especially the reference point and the longitudinal point of 15^0 have comparatively more brightness to the rest of the papers. This might have had happened because the rest of the pulps were prepared after a couple of months when they were cut for the longitudinal grinding. The wood cubes had some black spots because of long storing into the store. This might be one of the reasons considering to the weak brightness of the subsequent papers. In addition, the effect of brightness could have been affected by the level of fines present in the pulp.

11.2.3 Air Permeability

Using the Bendtsen tester, air permeability of the papers was measured in ml/min. The mean of ten test sheets for every point of pulp were calculated and the results are represented in the following graph:

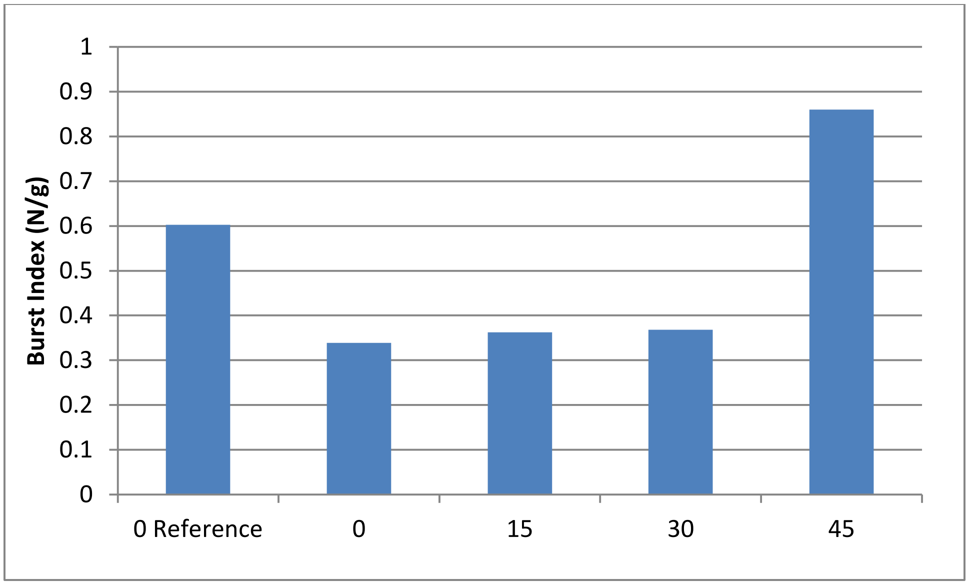


Graph 7 Air Permeance (ml/min)

The graph shows a complete progression in the air permeance to the longitudinal grinding. The reference point has higher air permeability than the longitudinal point at 0^0. In other cases, the air permeance is increasing as the degree of inclination increases as per the longitudinal grinding but finally decreases at 45^0.

11.2.4 Bursting Strength

Burst-O-Matic gave the measurements of pressure resistivity of the papers in kPa. Two tests were done for each sheet. From the mean of all the measurements, burst index was calculated by dividing the bursting strength with the basis weight of the papers. The results are shown in the following graph.

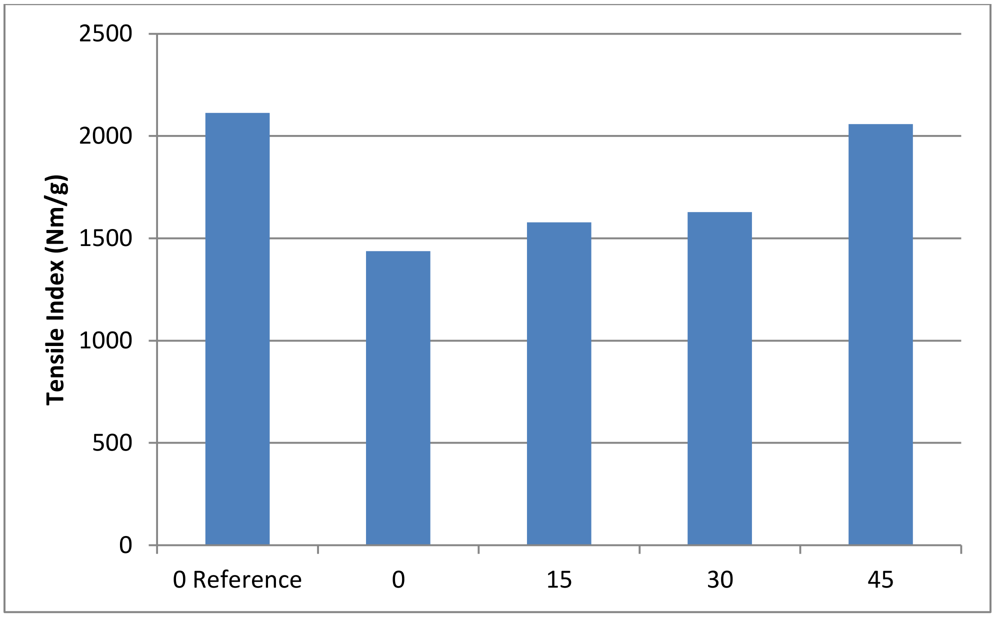


Graph 8. Burst Index

The burst index shows that the paper is in increasing order for longitudinal grinding. The bursting strength is much higher in the 45^0 of longitudinal grinding. They are at constant rate going from 0^0, 15^0 and 30^0 of longitudinal grinding. The longitudinal grinding could actually help develop the pressure resistivity of the papers.

11.2.5 Tensile Strength

The tensile strength of every test sheet was measured in Newton (kN/m) and the result is used to calculate the tensile index. The result is in the following graph;

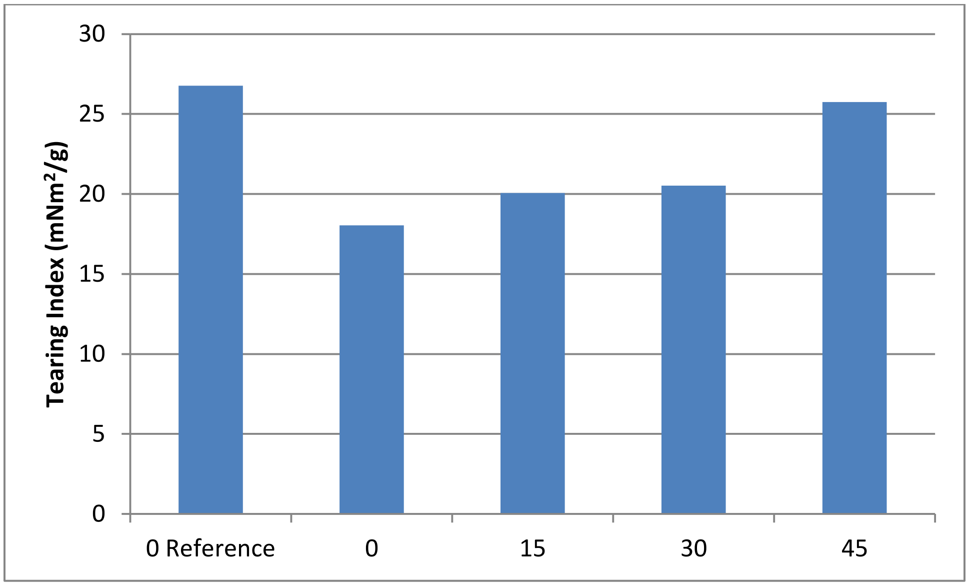


Graph 9 Tensile Index

The graph of tensile index actually agrees with that of the bursting strength. There is a progression of the tensile strength of the papers as the longitudinal grinding proceeds. And, there is a constant or almost same tensile strength for the papers of longitudinal grinding of points 0^0, 15^0 and 30^0. However, the tensile strength is at a highest range for the 45^0. We can assume that the tensile strength of the paper could actually be developed by applying longitudinal grinding.

11.2.6 Tearing Strength

The tearing strength of all the test sheets was measured in mN. Dividing with the basis weight, tearing index was calculated. The mean results for each point of papers are represented by following graph;



Graph 10 Tensile Index

This graph also explains the same illustration. The tearing strength of the papers is same like that of the tensile strength of the same papers. There is a slight increase of the tearing strength from 0^0 to 30^0 of longitudinal grinding whereas it grows drastically at a highest point in 45^0. Anyway, the tearing strength could also be increased by the longitudinal grinding.

12 CONCLUSION

In this work, the properties of pulp and paper obtained from longitudinal grindings of aspen were investigated. The angle of inclination in the longitudinal grinding came out to be essentially important in the products of pulps and papers obtained. The nature of the pulps and papers actually depended on the style of grinding. As compared to the traditional grinding as a reference, the longitudinal grinding takes much in account in the papers of better strength properties as a bi-product.

From the acquired results of this work, one can draw the conclusion that in principle, the strength properties of the papers obtained from longitudinal grinding have much influence on the one with 45^0 inclinations. The main properties of the papers such as bursting strength, tearing strength and the tensile strength shows a progression in accordance to the longitudinal grinding of aspen. But, the air permeance also shows increasing, that could be a negative feedback for the longitudinal grinding. The conclusion was made to identify which angle for the longitudinal grinding develops the strength properties to the papers better.

It was important to know the behavior of pulp before the papers were made from each point after the grinding. Combining all the results, some results especially emphasizing the one with the 0^0 of the longitudinal grinding shows much discrepancy. The result draws more differences than the expected values. Furthermore, the freeness of 45^0 longitudinally ground pulps shows the result other way around. Experimental errors could be drawn regarding the unexpected results.

Nevertheless, the applications of longitudinal grinding are important in the field of pulp and paper industry. Developing the strength properties of the products from longitudinal grinding draws increased efficiency of mechanical pulping method. Longitudinal grinding could serve the requirement of high quality papers.

FIGURES

Figure 1. Longitudinal Grinding 4
Figure 2. Laboratory Grinder........ 13
Figure 3. Traditional Grinding and Longitudinal Grinding........ 14
Figure 4. Pressure Filtration........ 15
Figure 5. Moisture Analyzer 16
Figure 6. CSF Tester........ 17
Figure 7. Laboratory Centrifuge 18
Figure 8. Micrometer........ 20
Figure 9. Elrepho Tester........ 21
Figure 10. Bendtsen Tester 22
Figure 11 Burst-O-Matic……..24
Figure 12. Tensile strength tester 25
Figure 13. Elmendorf-type tester........ 26

TABLES

Table 1. Fiber Length measurement 27
Table 2. Water Retention Value Calculations 30

GRAPHS

Graph 1 Fiber Length Measurement 28
Graph 2. Freeness Measurement........ 29
Graph 3 Water Retention Value........ 30
Graph 4 Density Variations........ 31
Graph 5 Variations in the bulk 32
Graph 6 Brightness and Opacity........ 33
Graph 7 Air permeance (ml/min)........ 34
Graph 8. Burst Index........ 35
Graph 9 Tensile Index........ 36
Graph 10 Tensile Index 37

REFERENCES

1. American Hardwood Export Council, 2002 (http://www.ahec.org/hardwoods/guide/aspen.html)

2. Impregnation ability of European aspen (populas tremula L. and Birch (Betula Pendula Roth.) Wood as fast growing trees. By Kazimierz Lutomski, Grzegorz cofta and Bartlomiej Mazela.

3. National Research Council (U.S.). Subcommittee on Underutilized Resources as Animal Feedstuffs, p 75-77. (www.books.google.fi/books/chemical_composition_of_aspen)

4. Western Excelsior Corporation (http://www.geosolutionsinc.com/documents/WE_EXCEL_AEL_ALL.pdf)

5. Papermaking properties of aspen ultrahigh-yield mechanical pulps, McGovern, J. N.; Wegner,
   T. H. Tappi journal. Vol. 74, no. 8 (Aug. 1991): Pages 157-161. (http://www.treesearch.fs.fed.us/pubs/30531)

6. Alkaline Extraction of Hemicellulose from aspen chips and its impact on subsequent kraft pulping
   Waleed Wala Al-Dajani and Ulrike Tshirner
   (http://www.tappi.org/content/events/07epe/papers/07EPE33.pdf)

7. Paper industry technical association (http://www.pita.co.uk/factsheets/public_view.php?id=161)
8. Handbook of Mechanical Pulping, Second Edition, Edited By: Bruno Lönnberg, 2009. P. 18-22, P. 70-72, P. 140-142

9. Screening of pulp (Somerville-type equipment) (Reaffirmation of T 275 sp-02) (http://www.tappi.org/content/tag/t275.pdf)

10. Engineering Aspects in Solid-Liquid Separation. By. Josh Harberthal, (http://www.solidliquid-separation.com/pressurefilters/pressure.htm)

11. A comparative study of two automated techniques for measuring fiber length
M. GRAÇA CARVALHO, PAULO J. FERREIRA,
ALEXANDRE A. MARTINS AND M. MARGARIDA FIGUEIREDO

12. Effect of Pulp Fines on the Dye−Fiber Interactions during the Color-Shading Process, August 17, 2010
(Hongbin Liu, Shuhui Yang and Yonghao Ni)

13. Handbook of pulp, Edited By; Herbert Sixta.
Page 3. Fibers. 2006 WILEY-VCH Verlag GmbH &Co. KGaA, Weinheim

14. Mini-Encyclopedia of Papermaking Wet-End Chemistry
(http://www4.ncsu.edu/~hubbe/Defnitns/Freeness.htm)

15. Scandinavian pulp, paper and board testing committee
SCAN-C 62:00. Accepted 2000

16. Booklet Printing, LLC
(http://www.bookletprint.com/2010/02/paper-opacity-whiteness-brightness-shade)

17. Properties of Paper
(http://www.biltpaper.com/atoz2.asp)

Fiber length measurement (0 Reference)		
Range	0.00 - 7.60	
	Cont.	Proj/mm
L(n)	0.2	0.18
L(l)	0.43	0.36
L(W)	0.7	0.54
Fines(n)	63.93	66.97
Fines (l)	25.1	29.87
Fibers measured	18425pcs	

Fiber length measurement (0^0)		
Range	0.00 - 7.60	
	Cont.	Proj/mm
L(n)	0.06	0.05
L(l)	0.14	0.12
L(W)	0.32	0.27
Fines(n)/%	96.42	97.13
Fines (l)/%	79.64	84.17
Fibers measured	15716	

Fiber length measurement (15^0)		
Range /mm	0.00 - 7.60	
	Cont.	Proj/mm
L(n)	0.11	0.1
L(l)	0.27	0.23
L(W)	0.45	0.38
Fines(n)/%	82.84	85.52
Fines (l)/%	47.02	53.62
Fibers measured	16401	

Fiber length measurement (30^0)		
Range /mm	0.00 - 7.60	
	Cont.	Proj/mm
L(n)	0.08	0.07
L(l)	0.2	0.17
L(W)	0.48	0.34
Fines(n)/%	91.58	93.23
Fines (l)/%	66.27	72.07
Fibers measured	20858	

Fiber length measurement (45^0)		
Range /mm	0.00 - 7.60	
	Cont.	Proj/mm
L(n)	0.08	0.07
L(l)	0.22	0.19
L(W)	0.45	0.37
Fines(n)/%	0.73	92.24
Fines (l)/%	61	66.48
Fibers measured	16096	