LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
Department of Mechanical engineering
Degree Program in Packaging Technology

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PRESSFORMING OF A TRAY FROM A PULP SHEET

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ABSTRACT

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The aim of this thesis work was to verify the possibility to produce tray packages directly from pulp sheets using press forming techniques. The different existing raw materials of pulp, various sources of molded pulp and different methods of production of molded pulp were studied. Nine different raw materials which were used for experimental work were provided by *Stora Enso mills,* and *Stora Enso Research Centre, Imatra, Finland*. The laboratory tests were carried out using LUT Adjustable packaging line at *Lappeenranta University of Technology*. The results prove that long virgin fibres of pine pulp seems to have better formability with high moisture content compared to others. No significant improvements were noticed with conditioned samples, never the less far studies has to be done to find optimal conditions for production. The results indicated the possibility for making pressformed tray from two different pulp qualities (*Sunila pulp and Enopine*). The method could prove to be beneficiary as the production line could be shortened and

investment in board machines could be avoided if the trays were pressed directly from pulp sheets. Also the labour costs would be reduced. However, there is much work to be done before the quality of a tray produced out of a pulp sheet is comparable to a tray produced out of tray board.

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December 2014, Lappeenranta, Finland

Niraj Panjiyar

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LIST OF SYMBOLS AND ABBREVIATIONS

BCTMP	:	Bleached chemi-thermo-mechanical pulp
BHF	:	Blank Holding Force
CTMP	:	Chemi-Thermo Mechanical pulp
CAD	:	Computer Aided Design
CMP	:	Chemi-Mechanical Pulp
LUT	:	Lappeenranta University of Technology

1. INTRODUCTION

The largest volume of egg trays produced in Europe and North America are generally made from molded pulp. [1] [2] In early days, molded products of pulp were limited to egg trays but today molded products are commonly used for numerous purposes [3]. Historically, the credit for inventing the tray box goes to "Martin Keyes" who was a proficient inventor in the late 1800s. He invented Keyes Fibre, paper-plate molding machine which had the capacity of producing 50,000 pieces per day [4]. He also invented products like bottle packs, container for light bulbs and fruit, and vegetable packaging. [5]

Nowadays, molded products seem to be used as primary and secondary packages in many other forms due to its sustainability qualities. The state of art process for making molded pulp products has increasingly made it easier for firms to plan different molded pulp packages. [1] As firms think about materials sustainability when making packages, molded products could be made from recycled fibres and scrap materials that could be recycled and used all over again. [6]

Molded pulp products are generally made from a water slurry of fibres by the use of a spongy mold that is completely immersed into this slurry after which the mold is compacted into a sister mold also with pores, so the surplus slurry and liquid will drain out. This method makes use of a suction method to assist while coating the mold with slurry and compressed air to support to release the molded part which is formed between the two halves. Afterwards, the molded part is dried in a kiln or in a drying camber. [1] [7]

Typically the molded pulp products are divided into 4 categories:

1. Thick walled mold:

This is usual in size ranges from 3/16 to 3/8 inch thick, made from scrap and Kraft paper. This type of mold pulp is mostly casted in primary packages for holding objects for safe shipping purposes. This is also called plain molding e.g. nursery pots. [8]

Figure 1 .Thick walled mold. [8]

2. Transfer mold:

This is usual in size ranges from 1/8 to 3/16 inch thick. This is also called precision molding. As the pulp is transferred from one mold to other, both parts are completed, hence named as transfer mold e.g. egg cartoons, table wares, fruit and drink trays. [7]

Figure 2.Transfer mold. [8]

3. Thermoformed mold (thin wall):

The used molds are heated which makes the product more exact in shape and the material denser. The molded products have features of plastic materials e.g. thermoformed plastic materials. [7] [9]

Figure 3. Thermoformed mold [8]

4. Processed mold:

This is used for further processing of thermoformed mold. In this case, in molds there are neither additives nor coating materials. It uses secondary or other special treatments than simply being molded or cured e.g. die cuter perforated materials. [10]

Figure 4.Processed mold. [8]

The aim of this thesis work was to make a pressformed tray from different pulp sheet materials with the LUT adjustable packaging line, in order to find other ways for production than via the water slurry process.

1.1 Existing Raw Materials

Various possible fibre raw materials that could be used to manufacture molded products are listed below. Pulp molds is typically made from recycled paper board and news print. [11] These fibres can be divided into

a) softwood
b) hardwood
c) Non-wood fibres

There are different pulps produced from different wood types. Among hardwoods eucalyptus, acacia and birch are used as pulp raw material. Also aspen can be used as chemical pulp raw material, but usually it is used for BCTMP (bleached chemi-thermo-mechanical pulp) production. [7] It is a process of pulping in which sodium sulphite is used for impregnation. [12] Pulp made from pine species are typically produced using Kraft processes. The unbleached pulp of wood chips is produced by mixing sodium hydroxide (soda liquor). [13] The unbleached pulp can further be bleached. Spruce is mainly used as raw material in the production of mechanical pulps.

Hardwood pulp is made from the most of angiosperm trees. They are used for papers in which good printing properties and opacity are required e.g. fine papers, printing papers and art papers. Earlier studies have shown that good bonding capacity, bulk and opacity are achieved from birch pulp. [7] Generally, softwood has high strength properties; tensile and tearing strength. Good strength provides outstanding runability in paper machines, coaters and printing presses. For writing and printing papers, high quality wrapping papers and board production, bleached softwood pulp is used. Reinforcement pulp is a chemically produced fibre component, which purpose is to give sufficient strength properties to the finished paper. [11] [7] [14]

Reinforcement pulp includes 70-80 % spruce and around 20-30 % pine. A good reinforcement fibre is elastic, long and strong. [7] The process of removing some of the trees from the forest is called forest thinning. Thinning of forests is done to promote and improve the growth of the tree stand remaining. The time it takes for the tree to grow from a sapling into a tree that is ready for final cutting or regeneration cutting is called the rotation time. [15]

1.1.1 Softwood

In Finland, softwoods as pine (*Pinus Sylvestris*) and spruce (*Picea abies*) are the domestic softwoods for paper manufacturing. [7] A major percentage of the world's papers are produced using trees grown in temperate climate zones. Efforts are also made to cultivate these trees in subtropical and tropical zones to ensure the production of long-fibre pulps. Long-fibre species, which are suitable for paper production, are not indigenous to these areas. [6] The similar sorts of softwood species are also used in Europe and Asia, with deciduous types being used to a certain extent. Larch does not seem to be suitable raw material as it has a high extractive content compared with pulp from spruce and pine. On the other hand, North American softwood species differ from European and Asian species. For example, in fast-growing farmstead forests such as in South America and New Zealand, radiate pines are often used. [7] In softwood of same species the chemical composition doesn't vary much. The extreme difference seems to be found in extractives content. [11] The volume of softwood fibres used in pulp fabrication does not differ significantly. Pine is typically produced using the sulphate method; the raw material for production of mechanical pulps is spruce. [16]

Pine pulpwood

There are different species of pines tree. The most common pines used are Radiata pine, Scots pine and Lodge Pine. The rotation cycle of northern pine is between 60 to 100 years. The first thinning takes place between 30 – 40 years, before harvesting. The rotation cycle of Radiata pine is from 20 to 30 years. Lodge pole and slash pines are cultivated in South U.S., where their rotation cycles are also about 30 years. The cell walls of pines are thick and rigid so they need chemical and mechanical treatment to break down. Their primary function is to generate strength to fibre based products. [16]

Spruce pulpwood

The rotation cycle of spruce is from 60 to 100 years. The first thinning is carried out usually when the trees are about 30-40 years old. A second thinning usually precedes regeneration cutting. The specific gravity of spruce is approximately 440 kg/m3. It is the most common wood species used in grinding processes. In many parts of Europe and North America, spruces are the most important commercial wood raw material for ground wood processes. Spruce has good tensile strength and good brightness properties. [16]

Softwood fibre

In general, softwood is formed of two types of cells: tracheid's (90-95%) and ray cells (5-10%). Softwood fibre is another name for wood tracheid. Tracheids provides mechanical strength and transport water. The water transport occurs mainly by tracheids in thin-walled and large cavity early wood. Softwood fibres are sealed at both ends. The length of Nordic pine and spruce fibres is generally 2-4 mm and the average thickness is 1/100 of the length. [11] [17]

1.1.2 Hardwood

The Nordic birch *Betula pubescens* and *Betula verrucosa* are the oldest hardwoods used in pulp manufacturing. They have features such as longest and densest fibreed hardwoods. [11] Birch is used mainly in sulphate pulps and is commonly bleached. The *eucalyptus is* another important hardwood species. There are a wide range of different eucalyptus varieties, but only some can be used in paper production. These species are cultivated widely in South Africa, Asia, Australia and South America. In southern Europe and in Chile eucalyptus grows naturally. The most common method of producing eucalyptus pulp is using the sulphate process. In 1980 the global demand for eucalyptus pulp was 2.2 million tonnes, but by 2003 it had reached nearly 8 million tonnes, app. 40% of the world hardwood market pulp market. [18] Acacia species are the 3rd most important hardwood species. They are cultivated especially in Asia. The sulphate process is also frequently used for producing acacia pulp. Development of the plant breeding makes it possible to improve well-known hardwood species to a better and more efficient raw material source. New hybrids have been developed also from old eucalyptus species for improving the quality of pulp yields. In addition acacia and eucalyptus species have been examined to find varieties, which could grow in new areas. E.g. in China there are plans to expand eucalyptus plantations to more northern areas from South China, which requires varieties to have sufficient cold hardness. [11]

Birch pulpwood

After 30 - 60 years, birch is ready for logging. Around 80 years, it can be used for sawn timber. [11]

Aspen pulpwood

One of the world's most geographically widespread tree species is aspen. Especially in the production of BCTMP aspen is used. The rotation time for aspen is about 40 to 50 years, although 20 to 30 years is sufficient for pulpwood purposes. The specific gravity of aspen is 450 kg/m3. It has good light-scattering coefficient and brightness but poor bonding strength properties. In order to get good bonding strength it is usually treated with chemicals. [16]

Eucalyptus pulpwood

There are different species of eucalyptus but only few of them are important for chemical pulping. The tropical variety *Eucalyptus grand* grows in plantations. It has better fibre quality and processing features due to uniform quality in plantations. The diameters of logs that are delivered to pulp mill vary between 7 and 40 cm. The average rotation of forest under farming is around 14 years. [7] The harvesting time for eucalyptus is from 7 to 8 years. Eucalyptus first thinning is done after 4 to 5 years. Eucalyptus is a fast growing pulpwood suited well for cultivation. Cloning techniques have been developed for eucalyptus. The cloned trees have the same genetic properties. To be cloned, suitable buds are selected. The branches from the mother plant are cut smaller and the leaves are halved for growth of the seedling, so that they would not shade too much. A plastic funnel is used to grow roots in about a week. The funnel prevents longitudinal rises of the roots from the turning and the growth begins fast after the planting. The seedling is ready to be planted in about 6 weeks. The harvesting time is 22-24 years for *Eucalyptus globulus.* [11]

Acacia pulp wood

In the Pacific region, acacia is widely planted especially for paper pulp, fuel wood, construction wood, furniture wood and for erosion control. It is suitable for papermaking, but it has also some disadvantages. Due to the growing rate of a plantation acacia may be very high. Its average age is quite short but acacia grows fast some 30 to 50 years. The tree is growing very fast before 10 years. The trunk is straight and free of branches for over half of its height because the trees grow to a height of up to 30 meters. If the trunk is not straight and free of branches it is easily rotten and the barking is much more difficult compared to eucalyptus.
Pulping properties of acacia are similar to eucalyptus species. Cooking yield may be at level of 52 to 53 %. Acacia grows both in acidic soil conditions as well in neutral conditions. Eucalyptus has better impoverish on the soil compared to acacia but instead as a nitrogen-fixing tree acacia can even improve soil nutrient status. Eucalyptus plantations have not succeeded in Indonesia so acacia plantation is done there. [11]

Hardwood fibre

There are wide varieties of specialized cell types in hard wood. The main types of cells are vascular bundles and ray parenchyma made of huge hollow vascular cells and longitudinal storage parenchyma. There is a definite amount of other transitional cell sorts, such as tracheids in hard wood. The word 'fibre' denotes to all cells the working as maintenance cells. [1] The quantity of fibres in, for example, birch is 65-70% of all cells. This is considerably high, which causes serious problems in the use of hardwood pulps due to the percentage of parenchyma and, in particular, vascular cells. Hardwood fibres have denser walls and are smaller and thinner in size than softwood fibres. Hardwood fibres have a typical length of 1-2 mm and a thickness of approximately 0.025 mm, they contain considerably less holes than softwood fibres due to their smaller magnitude; hardwood fibres are significantly lighter than softwood fibres. [1] It could be said that, there is roughly 6-7 times the amount of fibres in a mass of hardwood pulp as there are in the equal mass of softwood pulp. The primary purpose of hardwood fibres is to support the trunk, while the same cells in softwood function both as support cells and vascular bundles. [11] [18]

1.1.3 Different sources for molded pulp

The moulded pulp can be made from different sources and each of them are described below

Newsprint

Newsprint is the most important produced paper grade used as a source for molded pulp. It consists of mechanical pulp and fillers and additives. It is usually a combination of over 90% mechanical pulp, less than 10% chemical pulp and at the most 15% filler. Most of the production is used as newspapers, but also magazines and other less demanding advertisement publications are printed on this paper quality. In flyers either standard newsprint or lighter, so-called improved newsprint can be used. Coloured newsprint is also used. News is the most standardized paper grade in the paper world. Smoothness and reliable runability is the most important technical properties of this paper grade. Usually it is produced as 45 g/m^2 or 42.5 g/m^2, but also 48.8 g/m^2 and 40 g/m^2 are in use commonly. Even thinner a paper is used in newspaper flyers. The average basis weight has decreased during the years. The use of lighter paper helps in savings in transport and handling costs. This trend may be coming to an end due to the increased use of recycled fibres. The portion of recycled fibre can be as high as 100% in newsprint. The magazines found in collected paper bring filler and pulp into recovered paper. The use of recycled fibre in paper and paperboard is by numbers means a new development, but due to the strengthening of the environmental standpoint its position is getting stronger. [11] [6]

Recycled pulp and other fibre raw materials

The recycling process involves use of recovered paper which is reduced to pulp predominantly by mechanical means, tailed by a deinking process. Recovered pulps are different when originating from virgin fibres. It is usually combinations of over 90% of mechanical pulp, less than 10% of chemical pulp and at the most 15% of fillers. [6]

In addition to ordinary technical paper properties, attention must also be given to pulp purity and any stickies present. If the intended use of the paper grade being produced is food packaging, any limitations on the use of recycled pulp must be determined at this stage. In making this determination, it is recommendable to compare recycled pulp made from wood-free recovered papers to chemical pulp and, correspondingly, recycled pulps made from wood-based recovered papers to mechanical pulps. [19]

The filler waste contained in wood-free printing papers compromises the value of this type of recycled pulp as raw material. In this case the impact may be considered comparable to its impact on a pure pulp stock. [11]

Conversely, the Y value of recycled pulp usually falls below that of mechanical pulp. In practice this means that the deinked pulp will have a greyish colour. As it contains chemical pulp, its light scattering coefficient and, in turn, it´s opacity is lower than found for a pure mechanical pulp. In spite of deinking, recycled pulp may have small spots of printing ink, which might compromise its suitability for reuse. [11]

The mechanical properties of recycled pulps made from wood-based printing papers are strongly dependent on the pulp's chemical pulp and filler content. The higher the chemical pulp content, the better the pulp strength properties, and the better they can be developed by refining. The percentage of chemical pulp improves tear strength. The technical paper properties of deinked pulp, particularly its brightness, vary more widely than the properties of mechanical pulp made from fresh wood. It is perfectly natural that variations in the composition of recovered paper are greater than those of the raw wood material. Variations occur in ash and chemical pulp content. The relatively low dispersion in brightness values in spite of their large range of variation demonstrates that extreme brightness values are a rare occurrence. [11]

Chemimechanical pulp

This grade is a cross over between chemical pulps and mechanical pulps. The chemi-mechanical pulping process is an adaptation of the TMP process, with the most significant difference being that chemical processing occurs before pulping in the mechanical pulp refiner. [11]

Chemi-mechanical pulps are abbreviated as follows:

- CMP or Chemi-Mechanical Pulp
- CTMP or Chemi-Thermo-Mechanical Pulp
- BCTMP or Bleached Chemi-Thermo-Mechanical Pulp

In the CMP process chip pulping in the pulp refiner occurs under normal pressure, while, in the CTMP process, the pulp refiner is pressurized (sealed). In practice chemi-mechanical pulp is usually same to CTMP, as refiners used today are nearly always pressurized. [11]

Development of the CTMP process has improved the possibilities of using a wider selection of raw material in production of high-quality paper and board grades. BCTMP pulp gives higher brightness compared to other mechanical pulps. BCTMP provides paper and board with higher bulk than chemical pulp. This means that paper users can use lower grammages, and lower their costs without sacrificing printability. [20]
There are synergies available when integrating a CTMP with a Kraft pulp mill

- in wood handling
- in effluent treatment
- in chemical recovery
- power generation
- in logistics
- in administration

Chemi-mechanical pulp can be produced using both softwood and hardwood. In Nordic countries the most common woods used as raw materials in chemi-mechanical pulps are spruce and aspen. Eucalyptus, maple and poplar are also used as wood raw material in Chemi-mechanical pulps. [11]
The chemical and morphological composition of different hardwood species varies much more than those of softwood species. Only a few hardwood species, such as aspen or poplar, can be used as raw material for purely mechanical pulp. Most species like eucalyptus, gamelan and birch need some kind of chemical treatment. Modification of the carbohydrates in a highly alkaline stage, combined with modification of lignin in a sulphite stage, can be useful in the pre-treatment of hardwoods. Despite that, processes based on either alkali or sulphite chemicals can also be successfully used for some species. [21]

Virgin fibres

Pulp made from improved paper principally differs from virgin pulp in that is has passed through the entire paper production process at least once, together with refining, the dosing of chemical additives, drying and calendaring. It has long been known that drying has an important impact on the technical paper material products of chemical pulp. The variations detected in products were greater the longer the chemical pulp was refined and the longer the intermediate drying was extended. It was also found that the higher the drying temperature, the more the properties of re-dissolved pulp differed from those of the original pulp. The decrease in strengths was at most approximately 35%. Conversely, if the refined pulp was freeze-dried, changes in properties occurred independent of the degree of pulp refining and the solids content achieved during drying. However, later studies showed that a majority of the differences in properties between virgin and once dried pulp are the result of irrecoverable structural alterations in the fibre membrane caused by drying . During drying, both the fibre lumen and the pores in its membrane are crushed. This causes bonding and hardening inside the fibre, which cannot be broken down during re-pulping. This hardening in the fibre effectively prevents it from swelling during reuse. This clearly demonstrates that, the more intensive and longer the initial drying phase, the greater is the impact on pulp properties during its reuse. Studies have also shown that a majority of the changes in pulp properties occur during the first drying cycle. Changes during subsequent drying cycles have much less impact. This is a clear demonstration of how the swelling capacity of chemical pulp fibre deteriorates after each use at a gradually decreasing rate. [11]

The effect of drying on chemical pulp fibre on the end product is much greater than its´ effect on mechanical pulp fibre and their properties. This is evidently due to the fact that the susceptibility of highly lignified chemical pulp fibre to crushing and shrinkage is much higher than to that of a much stiffer mechanical pulp fibre. The susceptibility of mechanical pulp fibre to swell is much lower than that of chemical pulp fibre. Thus, the effect on reuse of mechanical pulp properties is primarily due to its mechanical treatment. [11]

The greatest difference between the drying process and paper production process is that, the chemical pulp fibre in the former are dried carefully so that there is minimal inter fibre and internal fibre bonding. Conversely, maximum strength between inter fibre bonds are strived for during paper web formation and drying. The paper production process treats fibres more harshly than a chemical pulp drying machine, thus resulting in correspondingly greater impact on fibre properties after reuse. [11]

1.2 Existing Method

1.2.1 Fabrication method

The term ‘‘moulded pulp’’ is used to define product packaging and also food-service objects that are manufactured by making the object from an aqueous slurry of cellulosic fibres into distinct products on a screened, foraminate mould in a procedure similar to continuous-sheet cylinder board papermaking. Generally, the pulp-moulding process is found grouped with other adapting processes such as compression shaping of fibres- reinforced resin portions and pressboard transforming due to likenesses in concluding steps and mutual markets. The moulded pulp process and its products are primarily distinctive. Two basic methods of fabrication generally used are plain moulding and precision moulding. [11] [22] [23]

Plain molding

Goods of plain moulding are as essential as the three-sided bend protector plugs used in equipment and machine packing crates. Attractive surfaces can be applied by spray gun. Text such as product and end-user’s names and symbols like the recyclable logo or trademarks can be incorporated into the cast to produce a stamped or deposed result. [11] [23]

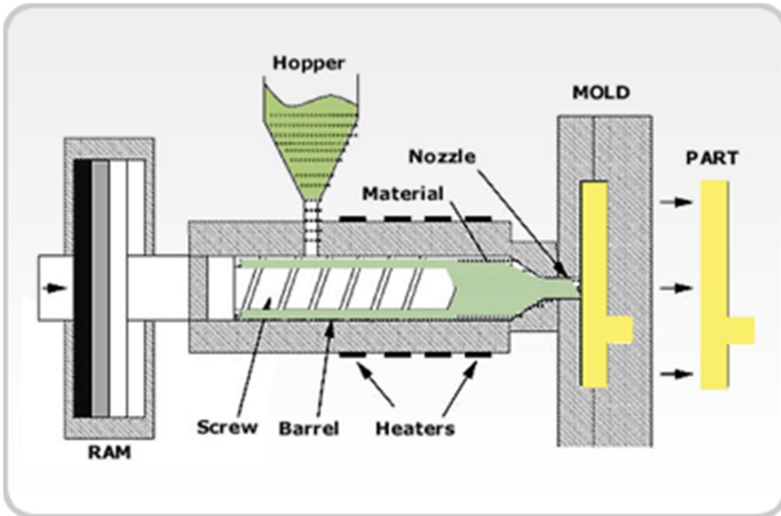


Figure 5. An example of plain molding equipment [24]

Precision molding

An example of subordinate treatment is the lamination of a tinny thermoplastic film to one surface of a moulded-pulp tray by vacuum-thermoforming methods. These type of products are being used for frozen foods because of their ‘‘double oven ability’’ i.e., their possibility for use in microwave and convection ovens. The use of computer-aided design has simplified the mould design and empowered more complex designs to be replicated than earlier. [11] [23]

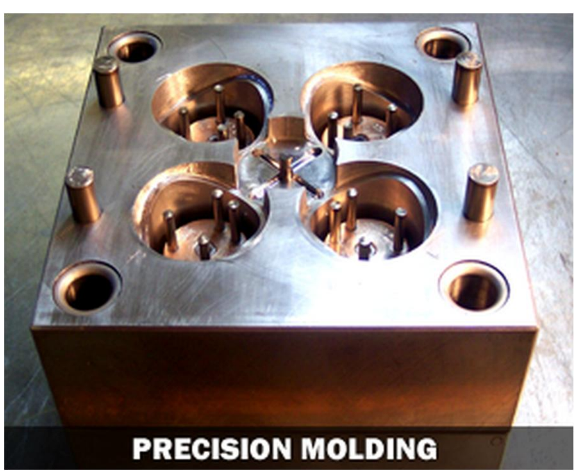


Figure 6. An example of equipment for precision molding [25]

1.2.2 Vacuum Filtration

In the vacuum filtration method, the force for filtration comes from the applications of pressure on the scum side of the medium. [23] Vacuum filtration is the principle on which pulp molding is designed and operated. The slurry is made up of cellulose and water to be filtered. The strong bonds are developed and enable them to retain their shape and contours when dried due to physical and chemical properties of cellulose. This technique is the manual technique of operation which is intended to keep the machine as simple as possible. [26] [27]

2. MATERIALS AND METHODS

There were 9 materials used in this thesis work .The materials were provided by Stora Enso Mills and Stora-Enso Research Centre, Imatra, Finland. The samples were obtained as bulk samples from full scale lines. All samples were supplied in sheet format.

Samples collected from Stora Enso Research Center, Imatra

1) Mänty (pine)
2) Koivu (birch)
3) Chemi-thermo mechanical pulp (spruce)
4) Sunila Pulp (pine)
5) Eno Alfa (mix of spruce and pine)

Samples provided by Stora Enso Mills

6) Enoforte EC-600 (mix of pine and spruce)
7) Enopine EC-100 (pine)
8) Koivu (birch)
9) Chemi-thermo mechanical pulp (spruce)

Sample 1 is a pine pulp sample provided by Imatra mills and represents a production sample; similarly samples 2 and 8 represent production samples of birch pulp from Imatra mills from two different sampling events. Sample 3 and 9 are production samples from Imatra mills CTMP-line from two different sampling events. Sample 4 is a production sample from Sunila mills. Sample 5 is a production sample of dissolving pulp from Enocell mills. Sample 6 is a production sample from Enocell mills containing both pine and spruce. Sample 7 is a production sample of pine from Enocell mills.

The samples were cut and tested in LUT packaging laboratory. The samples were cut to blanks with a Kongsberg XE 10 sample cutter. The blank was designed with CAD works and cut into a rectangular form with rounded corners (width 21 cm, length 25 cm) as show in figure 7. The sample blanks were individually placed in LUT packaging line´s molding section to form a tray. The important parameters for the work are blank holding force (BHF), moisture content and grammage. Blank holding force is the force with which the slide of the blank into the mold is controlled for maximizing the formability. [28]

Moisture content is determined as the percentage of water present in a sample by drying the sample to constant weight at 100 ^{o}C. The moisture of the samples was measured with oven drying method. [17].

Grammage is usually measured by mass and area (length and width) of a paper board [29]. In this experiment, the grammage of the samples were determined by cutting 10*10 cm^2 samples of the pulp sheets and weighing them on a Mettler laboratory balance and multiplying the results by a factor 100.

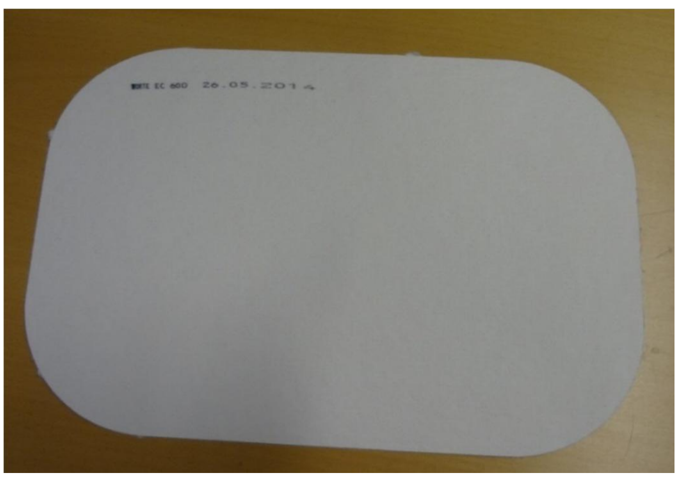
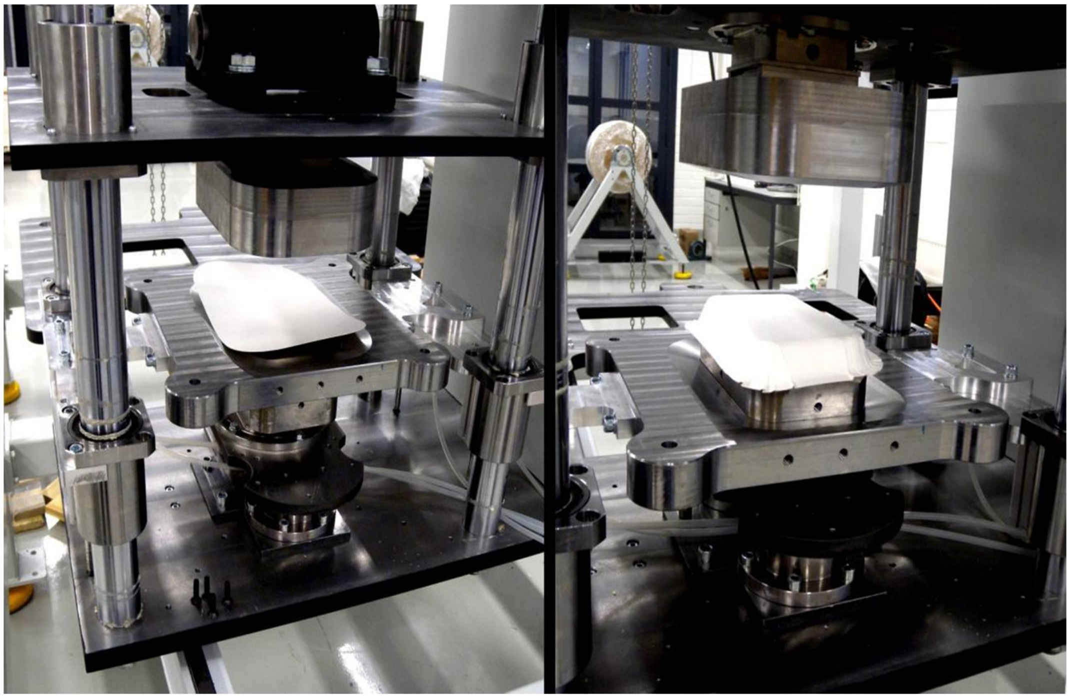


Figure 7. A blank sheet (21cm*35cm) cut with Kongsberg XE 10.

The samples were formed into trays with the forming module of LUT Adjustable Packaging Line.

The parameters for the lines were the mold temperatures, the forming speed, the pressing speed, the cycle time, the dwell time (time when molds are attached together in the forming process), and the blank holding force. Of these the blank holding force was varied while the other parameters were held fixed in order to evaluate the



strength and formability of trays made of different pulps.

Figure 8. A blank sheet and a pressed tray in the forming module of LUT Adjustable Packaging Line.

Figure 9. A blank sheet and a pressformed tray.

3. RESULTS AND ANALYSIS

The results of the experimental work are summarized in the following tables and graphs.

Table 1.The thickness, the grammage and the unconditioned moisture content of the samples studied

sample nr	samples	caliper(um)	gram mage (g/m^2)	unconditioned moisture %
9	CTMP Imatra Factory	1200-1250	340	8.09
3	CTMP Research Centre	1300-1400	360	7.66
7	Enopine	1000-1050	374	6.66
6	Enoforte	1300-1350	380	6.77
5	Alfa	950-1050	390	6.35
1	Manty	1100-1150	401	5.67
2	Koivu Research Centre	1200-1250	440	6.28
8	Koivu Imatra factory	1200-1300	442	6.29
4	Sunila Pulp	1850-2020	673	6.12

The caliper and the grammage in unconditioned form of the samples are given in table 1. In figure 10 the results are plotted. The overall trend is that the grammage increases with the thickness. In figure 10, 11 and 12 the order of the samples is given according to increasing grammage.

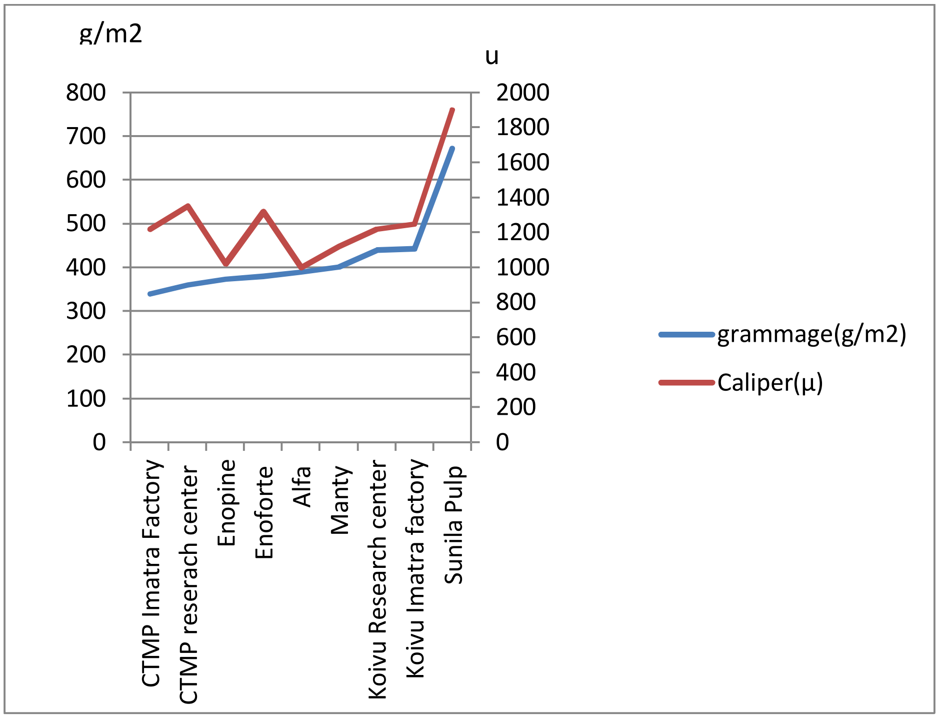


Figure 10.Comparision of the grammage and the caliper of the samples.

In table 2 the results from 1 week conditioning of the samples at 80% 23 °C are given.

Table 2. Grammage of the samples and moisture content in unconditioned state and after conditioning, 1 week at 80% RH at 23 °C

sample nr	samples	grammage (g/m^2)	Unconditioned moisture %	conditioned moisture %
9	CTMP Imatra Factory	340	8.09	10.13
3	CTMP Research Centre	360	7.66	9.33
7	Enopine	374	6.66	8.26
6	Enoforte	380	6.77	8.45
5	Alfa	390	6.35	10.96
1	Manty	401	5.67	7.92
2	Koivu Research Centre	440	6.28	6.91
8	Koivu Imatra	442	6.29	8.7

	factory			
4	Sunila Pulp	673	6.12	9.98

In figure 11 the effect of conditioning is illustrated. There exists variation in the behaviour of the samples as they are originating from different production times and the equilibration times are differing.

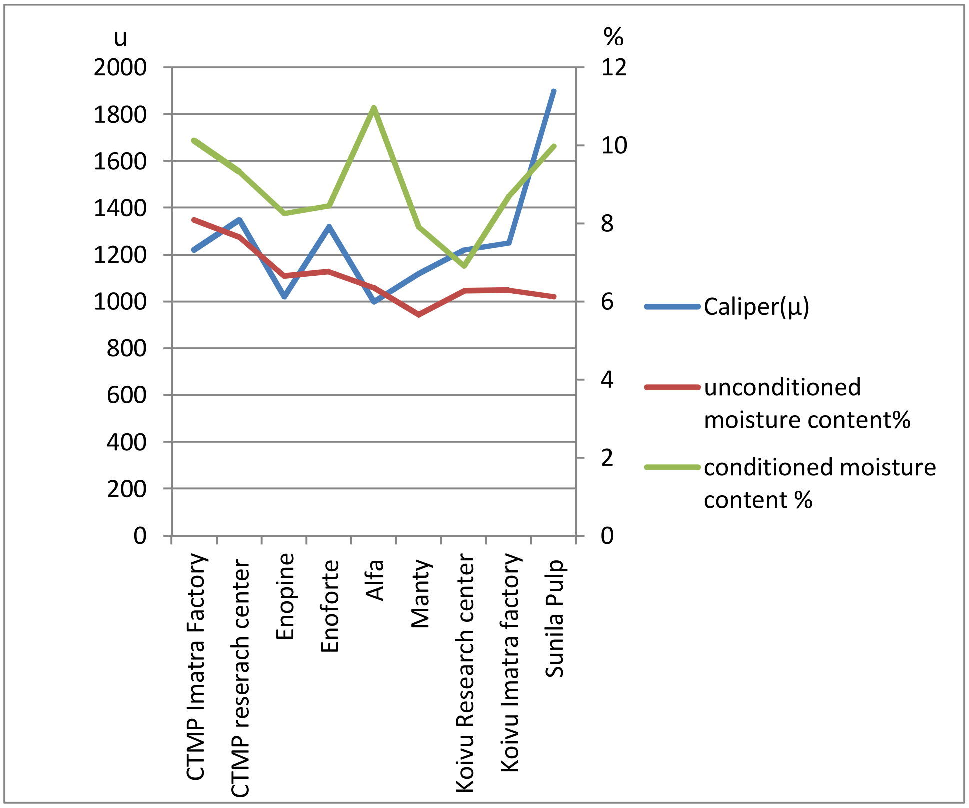


Figure 11. Comparison of unconditioned moisture content and conditioned moisture content with caliper.

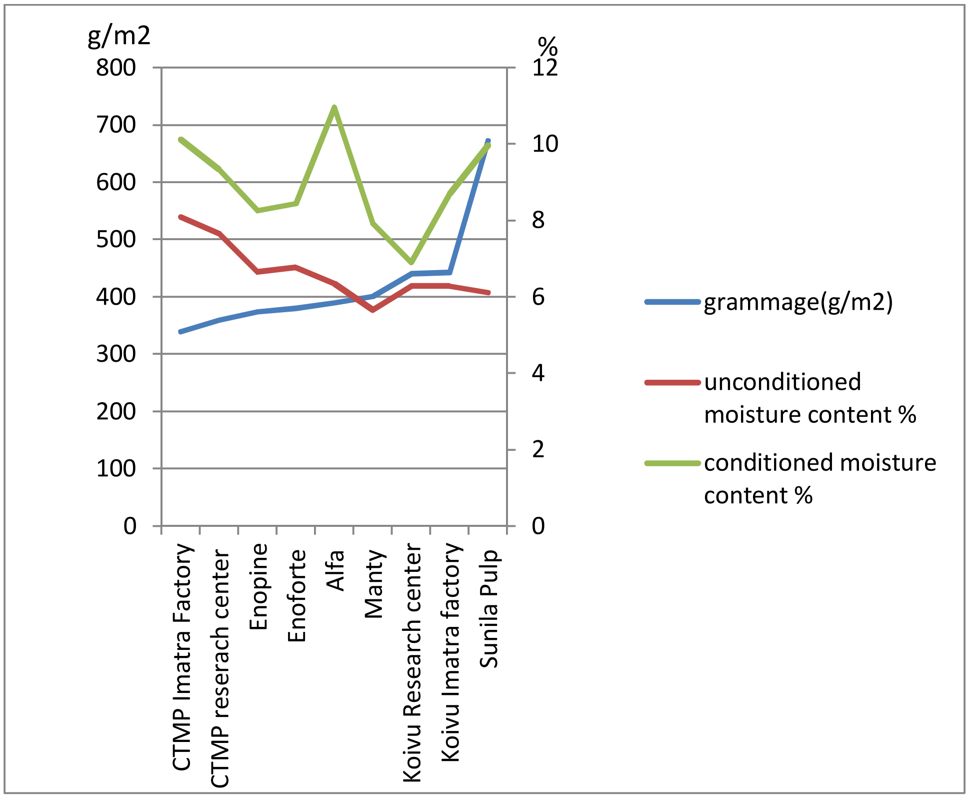


Figure 12. Comparison of unconditioned moisture content and conditioned moisture content with grammage.

From figures 11 and 12 it can be concluded that the environment in which the materials are stored affects the moisture content of the samples to some extent.

In table 3 and figure 13 the behaviour of sample 1 Manty in tray forming is given as unconditioned samples. From the graph it can be seen that the samples perform best with low BHF. However, 15 % BHF is not low enough to avoid ruptures in the corners. When testing sample nr 1 Manty as conditioned no improvement was observed. Errors were observed in previous table and graphs of Eno Alfa and Koivu Imatra in unconditioned form. The scale was retaken for these samples and a scale factor 1, 68 % was obtained for Eno Alfa and 1, 37 % for Koivu Imatra. These factors were multiplied with the original value of the unconditioned initial sample values. The new result of conditioned moisture content for Eno Alfa was 10,96% and Koivu

Imatra 8,7% were obtained. The moisture content was increased in case of conditioned form in all samples.

Table 3.The behaviour of sample nr1 Manty after tray forming as unconditioned

Sample nr 1 Manty			**(Pine)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15	2	10 cm ,9 cm	19cm
15	1	3cm	3cm
20	1	10cm	10cm
20	2	10cm, 6cm	16cm
35	4	12 cm, 9 cm,4 cm,8 cm	33cm

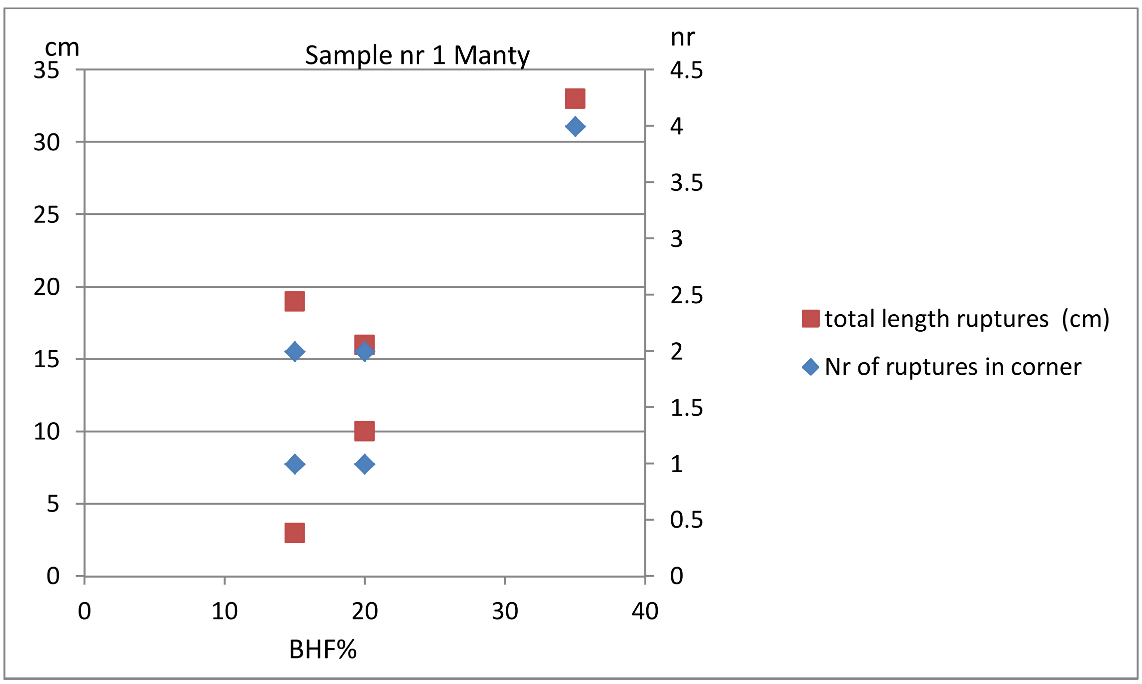


Figure 13. The behaviour of sample nr 1 Manty in the press forming with nr of ruptures in the corners.

The pictures with ruptures of sample nr 1 Manty are shown in Appendix 1

The pictures with ruptures with conditioned sample nr 1 Manty are show in Appendix 10.

The results for sample nr 2 Koivu (Research Centre) in press forming are graphically presented in figure 14. It can be seen that already at 15 % BHF ruptures were created. No improvement was observed in rupturing tendency after conditioning of the sample.

Table 4.The behaviour of sample nr 2 Koivu (Research Centre) after tray forming as unconditioned

Sample nr 2 Koivu Research Centre			**(Birch)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15	2	14 cm,10 cm	24 cm
15	3	21 cm,10 cm	31 cm
30	4	10cm, 11 cm,8 cm, 7 cm	36 cm
35	4	9cm,8 cm, 7 cm	24 cm

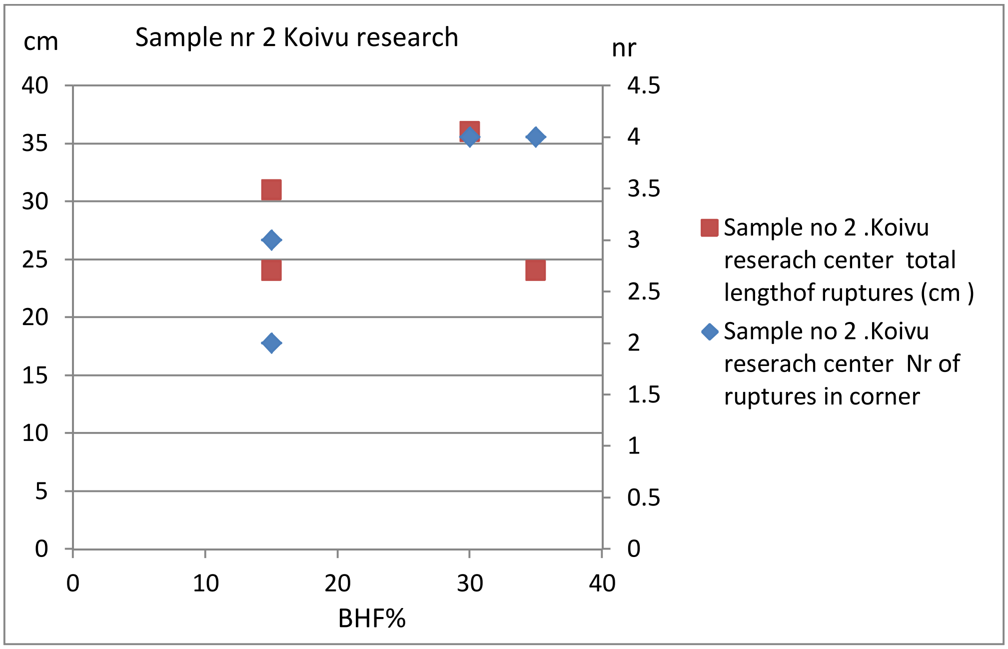


Figure 14. The behaviour of sample nr 2 Koivu (Research Centre) in the press forming with nr of ruptures.

The pictures with ruptures of sample nr 2 Koivu (Research Centre) are shown in Appendix 2.

The pictures with ruptures with conditioned sample nr 2 Koivu (Research Centre) are show in Appendix 11.

In table 5 and figure 15 the behaviour of sample 3 CTMP (Research Centre) is presented. Already with 15 % BHF rupture occurred in all 4 corners. Conditioning of the samples did not improve the results.

Table 5.The behaviour of sample nr 3 CTMP (Research Centre) after tray forming as unconditioned.

Sample nr 3 CTMP Research Centre			**(Spruce)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15	4	12cm,11cm,12cm,18cm	53 cm
15	4	12cm,10 cm,18 cm	40 cm

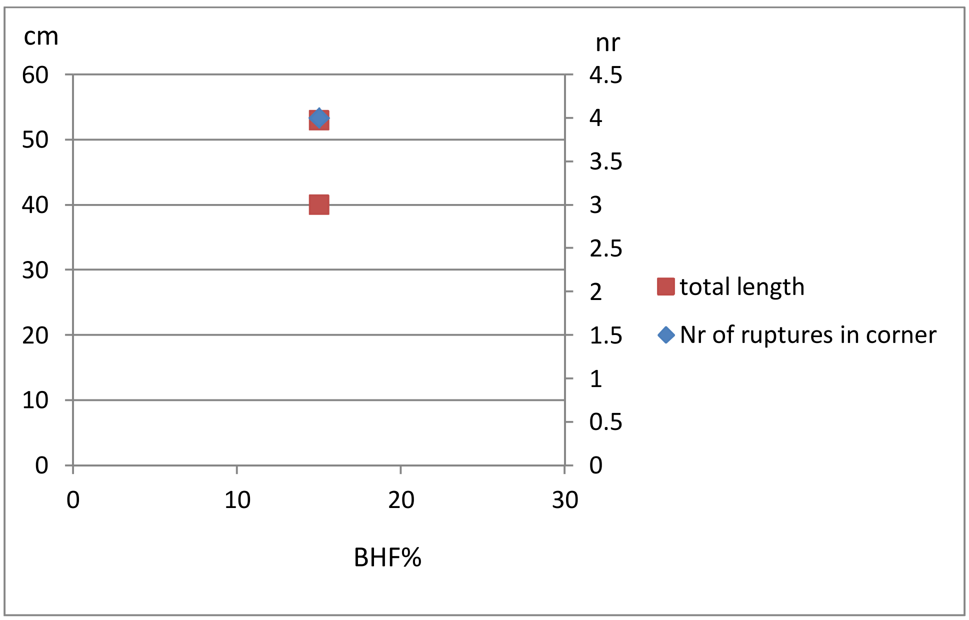


Figure 15. The behaviour of sample nr 3 CTMP (Research Centre) in the press forming with nr of ruptures in the corners.

The pictures with ruptures of sample nr 3 CTMP (Research Centre) are shown in Appendix 3

The pictures with ruptures with conditioned sample nr 3 CTMP (Research Centre) are show in Appendix 12.

In table 6 and figure 16 the behaviour in press forming of Sample 4 Sunila is presented as unconditioned. This sample tolerated a BHF level up to 30 %. The outcome of tests with conditioned samples was the same. This sample performed the best of all.

Table 6.The behaviour of sample nr.4 Sunila pulp after tray forming as unconditioned

Sample nr 4 Sunila			**(Pine)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15	0	0	0
20	0	0	0
25	0	0	0
25	0	0	0
30	0	0	0
35	1	3 cm	3cm

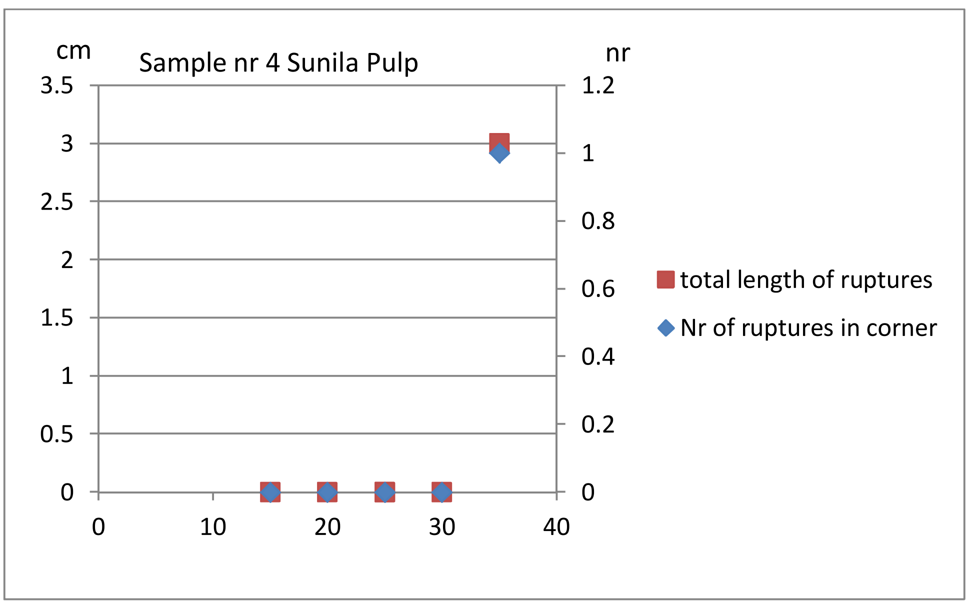


Figure 16. The behaviour of sample nr 4 Sunila in the press forming.

This figure show that samples nr 4 has only one rupture with 35 % BHF.

The pictures with ruptures of sample nr 4 Sunila pulp are shown in Appendix 4

The picture with ruptures with conditioned sample nr 4 Sunila Pulp are show in Appendix 13.

In table 7 and figure 17 the behaviour in press forming of Sample nr 5 Eno Alfa is presented in unconditioned form. Even at a low BHF value (15%) ruptures occurred in all 4 corners. No improvement in rupturing tendency was observed after conditioning.

Table 7.The behaviour of sample nr 5 Eno Alfa after tray forming as unconditioned

Sample nr 5 Eno Alfa (mix of spruce and pine)			**(Spruce and Pine)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15	4	25 cm, 31 cm	56cm
15	4	38 cm	38 cm

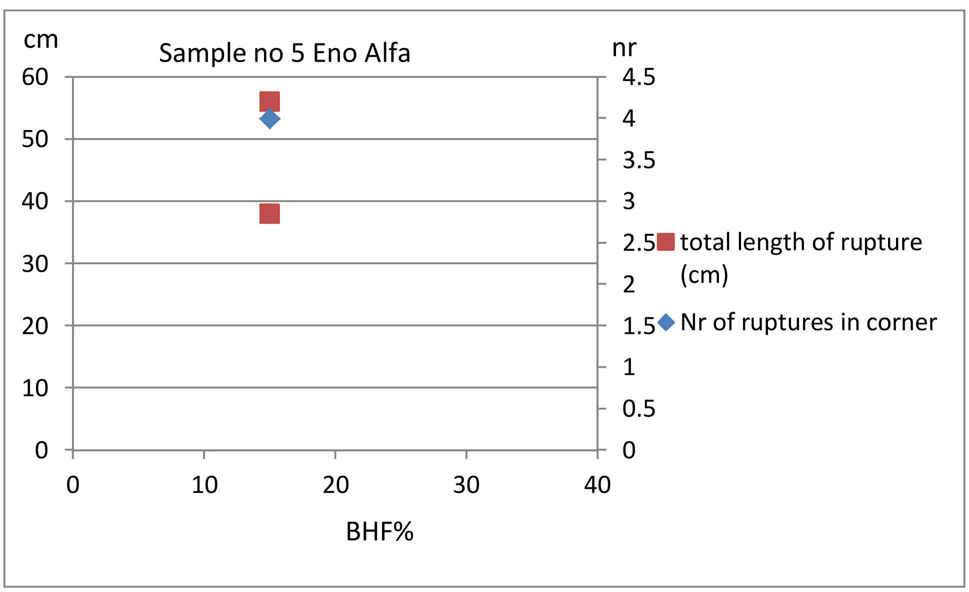


Figure 17. The behaviour of sample nr 5 Eno Alfa in the press forming with nr of ruptures in the corners.

The pictures with ruptures of sample nr 5 Eno Alfa is shown in Appendix 5

The picture with ruptures with conditioned sample nr 5 Eno Alfa is show in Appendix 14.

The behaviour of Sample nr 6 Enoforte in tray pressing is presented in table 8 and figure 18. The performance was not good enough at BHF 15 % for rupture free production in unconditioned form. No improvement in rupturing tendency was observed after conditioning.

Table 8.The behaviour of sample nr 6 Enoforte after tray forming as unconditioned

Sample nr 6 Enoforte			**(Spruce and Pine)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15	1	3 cm	3 cm
25	1	3 cm	3 cm
25	4	5 cm ,20 cm ,8 cm	33 cm
25	2	4 cm, 3 cm , 8 cm	15 cm
35	4	24 cm ,25 cm	49 cm

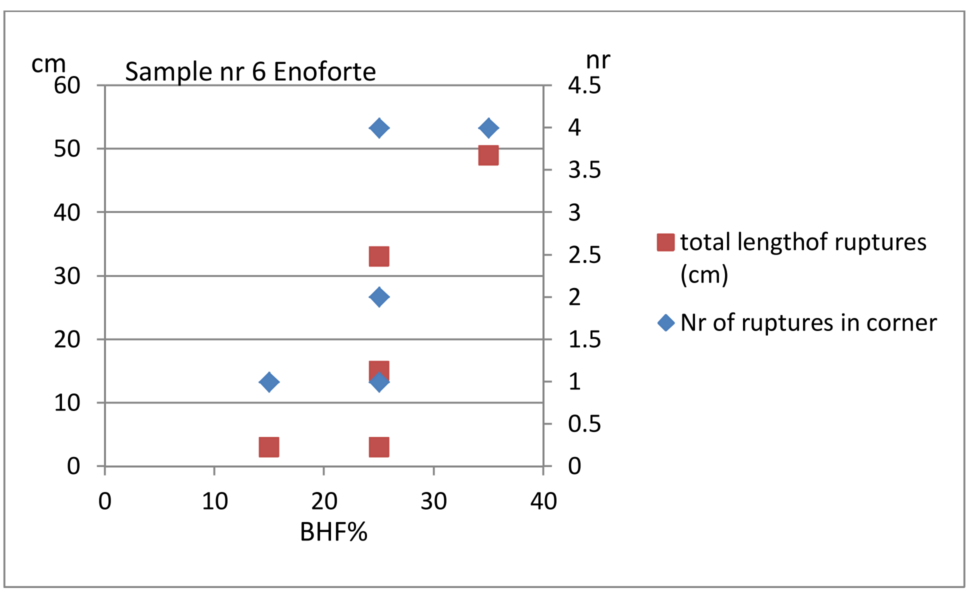


Figure 18. The behaviour of sample nr 6 Enoforte in the press forming with nr of ruptures in the corners.

The pictures with ruptures of sample nr 6 Enoforte are shown in Appendix 6.

The picture with ruptures with conditioned sample nr 6 Enoforte Pulp are show in Appendix 15.

In table 9 and figure 19 the results of sample nr 7 Enopine is presented after tray forming as unconditioned. For this sample it is possible to get unruptured trays with a BHF of 15 %. No improvement in rupturing tendency was observed after conditioning of this sample.

Table 9.The behaviour of sample nr.7 Enopine after tray forming as unconditioned

Sample nr 7. Enopine			**(Pine)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15			
20	**1**	**3cm**	**3 cm**
20	**1**	**4 cm**	**4 cm**
25	**2**	**7 cm, 9 cm**	**16 cm**
35	**4**	**20 cm 20 cm**	**40 cm**

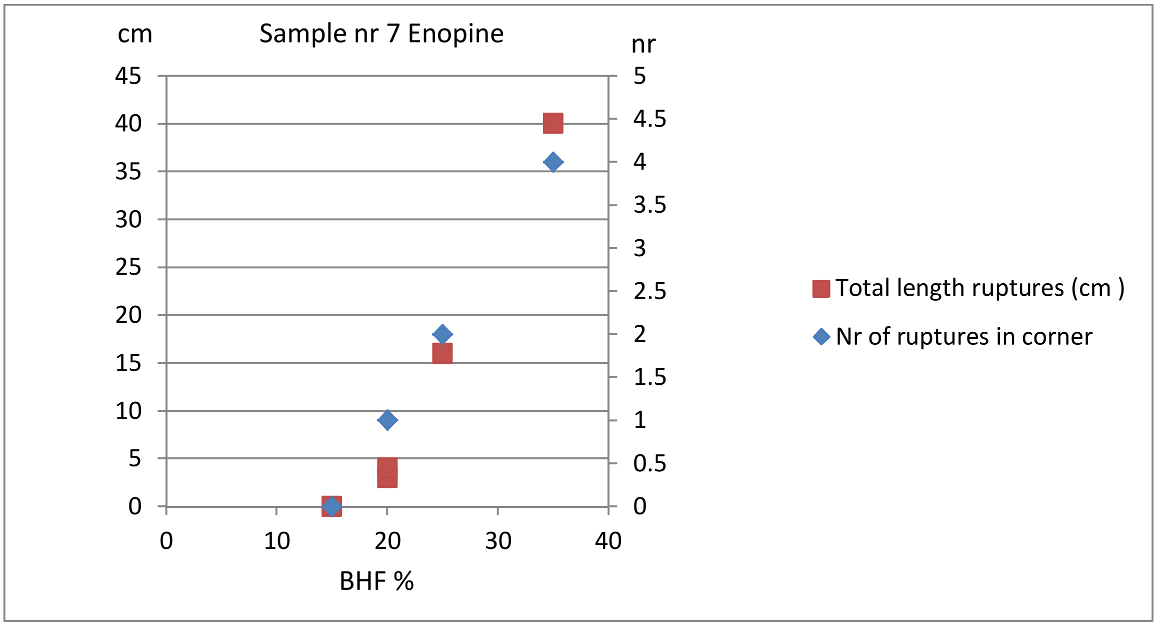


Figure 19. The behaviour of sample nr 7 Enopine in the press forming with nr of ruptures in the corners.

The pictures with ruptures of sample nr 7 Enopine are shown in Appendix 7.

The picture with ruptures with conditioned sample nr 7 Enopine is show in Appendix 15.

The results from tray forming of sample nr 8 Koivu (Imatra) in unconditioned form is given in table 10 and figure 20. Unruptured trays could not be produced even at BHF 15 % level. Conditioning of the sample did not improve the rupturing tendency.

Table 10.The behaviour of sample nr 8 Koivu Imatra after tray forming as unconditioned

Sample nr 8 Koivu Imatra factory			**(Birch)**
BHF	**nr of ruptures in corners**	**length of ruptures**	**total length**
15	2	13 cm, 11 cm	24 cm
15	4	10 cm ,2cm, 14 cm ,10 cm	36 cm

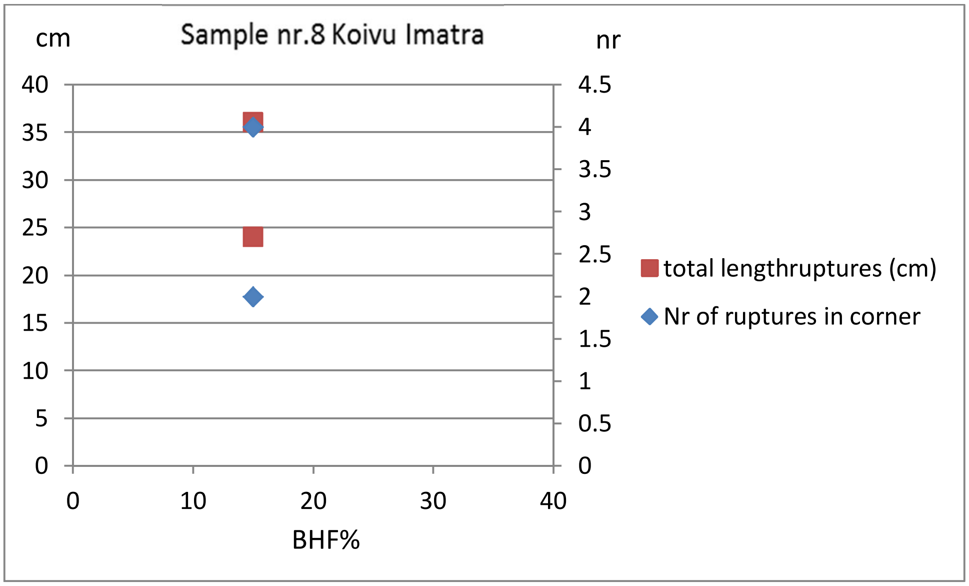


Figure 20. The behaviour of sample nr 8 Koivu Imatra in the press forming with nr of ruptures in the corners.

This figure shows that sample nr 8 Koivu Imatra have 4 ruptures with 15 % of BHF

The pictures with ruptures of sample nr 8 Koivu are shown in Appendix 8

The picture with ruptures with conditioned sample nr 8 Koivu Imatra are show in Appendix 17

In table 11 and figure 21 the results from tray pressing of sample nr 9 CTMP Imatra is given in unconditioned form. Ruptures occurred in all 4 corners even at BHF 15 % level. No improvements in the behaviour of rupturing tendency were observed after the conditioning.

Table 11.The behaviour of sample nr.9 CTMP Imatra after tray forming as unconditioned

Sample nr 9 CTMP			(Spruce)
BHF	**nr of ruptures in corner**	**length of ruptures**	**total length**
15	4	3 cm,3cm,3 cm, 9 cm	18 cm
15	4	4 cm,3cm,3 cm, 9 cm	19 cm

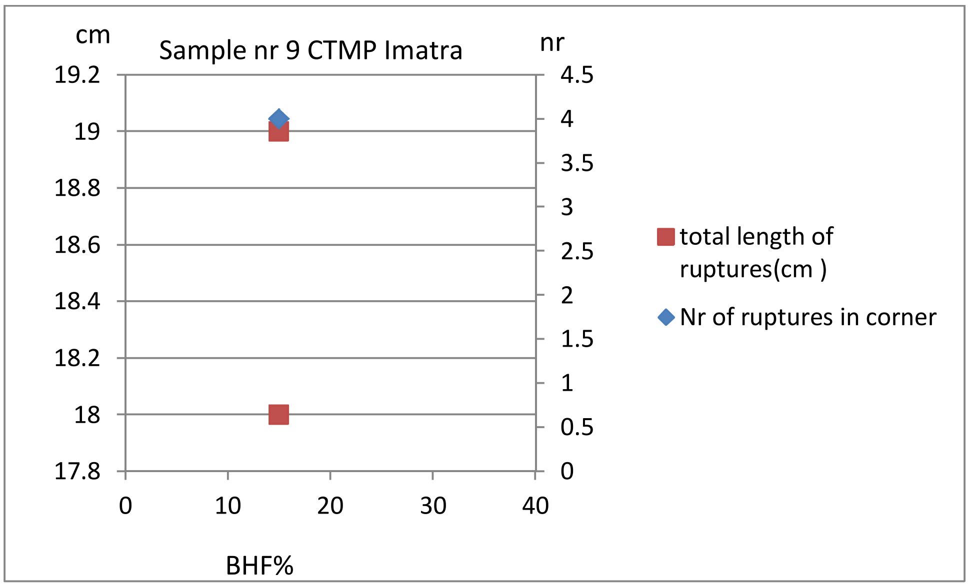


Figure 21. The behaviour of sample nr 9 CTMP Imatra in the press forming with nr of ruptures in the corners.

The pictures with ruptures of sample nr 9 CTMP Imatra are shown in Appendix 9

The pictures with ruptures with conditioned sample nr 9 CTMP Imatra are show in Appendix 18.

From above results it can be seen that sample nr 4 Sunila pulp performs best and tolerates most blank holding force in the forming process. Sample number 7 Enopine performs second best and tolerates a blank holding force of 15 %. The common denominator for these samples is virgin long fibre pine pulp. The caliper and grammage of Sunila pulp was clearly higher than in case of the other samples. The

Conditioning of samples had no effect in this study. For board-samples it is known that an increase of moisture content from about 5 % to 10 % improves the formability. This conditioning should be repeated in order to make any further conclusions of the observations. In figure 22 a summary of all samples are given regarding average rupture length and average rupture number for one tray.

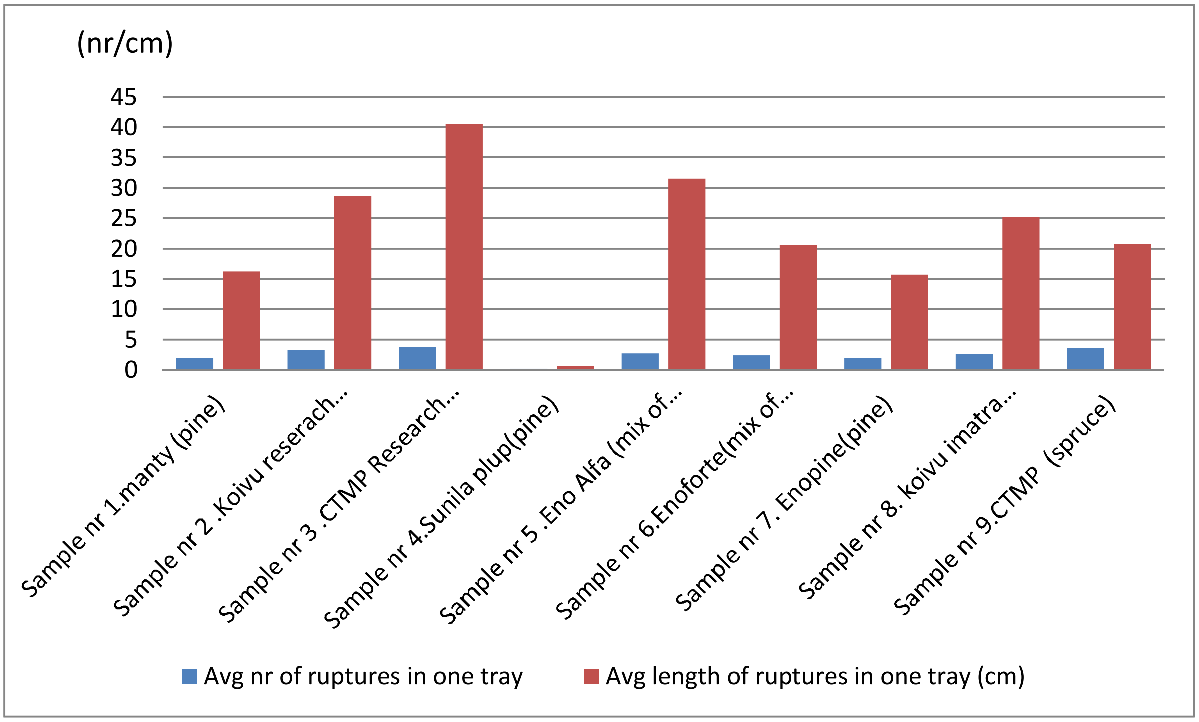


Figure 22. Results of all samples with average rupture length and number of ruptures for one tray.

4. DISCUSSION AND CONCLUSIONS

From above results it can be seen that sample nr 4 Sunila pulp has the best performance with least rupturing tendency and tolerates most blank holding force in the forming process. The caliper and grammage of Sunila pulp was clearly higher than in case of the other samples. Sample nr 7 Enopine was second best and tolerated a blank holding force of 15%. The characteristic features of these materials seems similar to pulp mold nr 2 thin walled transfer mold as described above in the introduction part.

The rest of the materials sample nr 6 Enoforte, sample nr 2 Koivu (Research Centre), sample nr 8 Koivu (Imatra Mills), sample nr 3 (CTMP Research Centre), sample nr 9 CTMP (Imatra Mills), sample nr 1 Manty, and sample nr 5. Eno Alfa did not respond satisfactorily although the blank holding force, speed and temperature were varied.

The same results were obtained with both conditioned and unconditioned pulp. This might be due to the fact that pulps differ in dry matter content.

The study was carried out with samples analysed as such when they arrived to the laboratory and after conditioning the samples at 80 % RH 23 ^{o}C for one week. The conditioning was expected to soften the pulp and give better formability. However, the effect was not seen.

The aim of this thesis work was to see if there is a possibility to produce tray packages directly from a pulp sheet using press forming techniques. If this would be possible then the production chain were paperboard is produced could be omitted giving reduced investment costs as well as reduced labour costs of the production process. From this study it can be seen that certain pulp qualities of sample nr 4 Sunila pulp and Sample nr 7 Enopine with 15% BHF have better potential than other for the purpose. Also the calliper of the materials correlates to some extent with the result. The clearance in the molds will be a matter of concern as the pulp sheets have considerably higher calliper than board material.

This study shows that it is possible with some pulp grades and certain production conditions to produce press formed articles. It might be possible to replace wet molded fibre articles with this technique but more studies are needed, particularly related to the conditioning of the samples to understand the limitations and possibilities of the technique.

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Appendix 1

Sample nr 1 Manty

Picture 1. Ruptures in sample Manty with 15 % blank holding force.

Picture 2. Ruptures in sample Manty with 20 % blank holding force.

Picture 3. Rupture in sample Manty with 35 % blank holding force.

Appendix 2

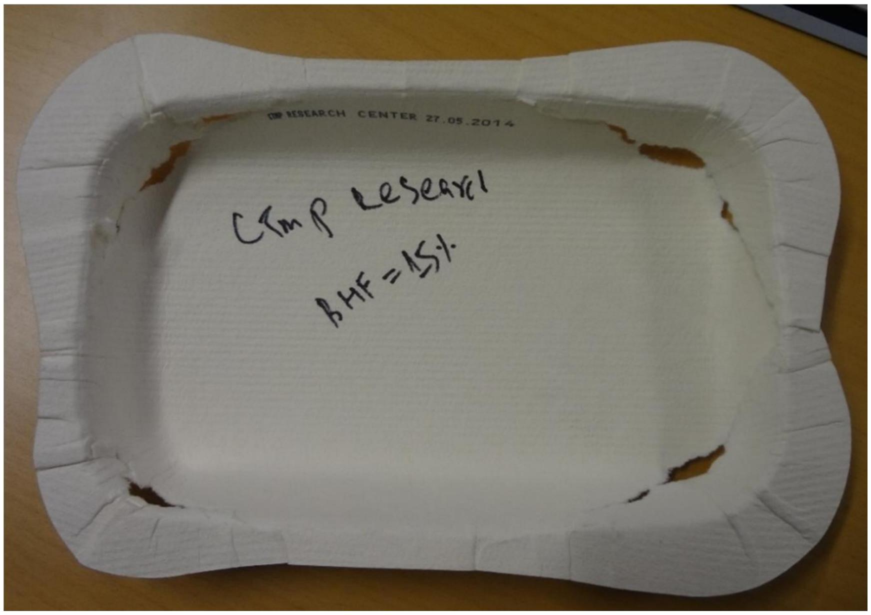
Sample nr 2 Koivu

Picture 4. Ruptures in sample Koivu research with 15 % blank holding force.

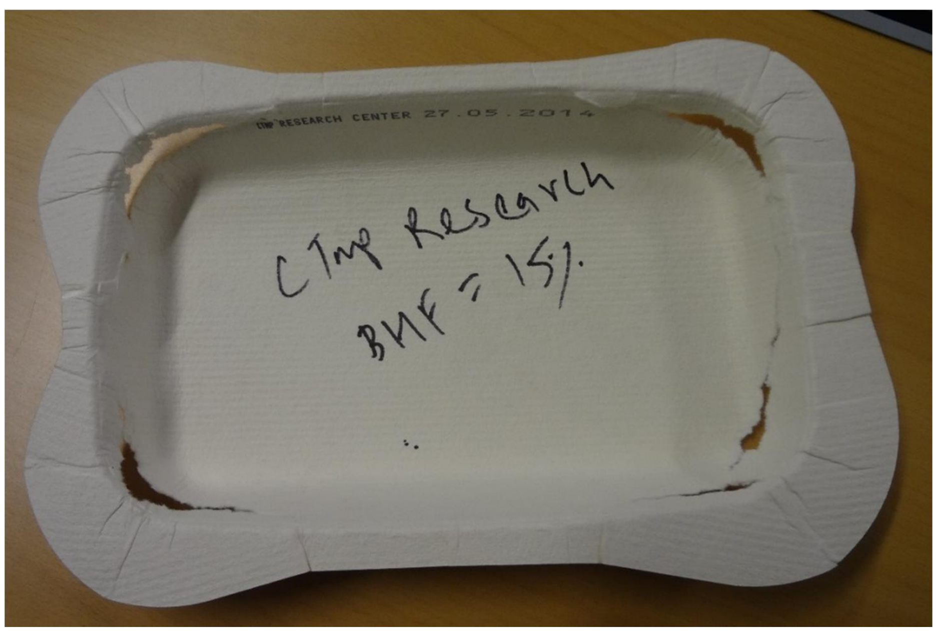
Picture 5.Ruptures in sample Koivu research with 15 % blank holding force.

Appendix 3

Sample nr 3 CTMP Research Center



Picture 6. Ruptures in sample CTMP Research center with 15 % blank holding force.

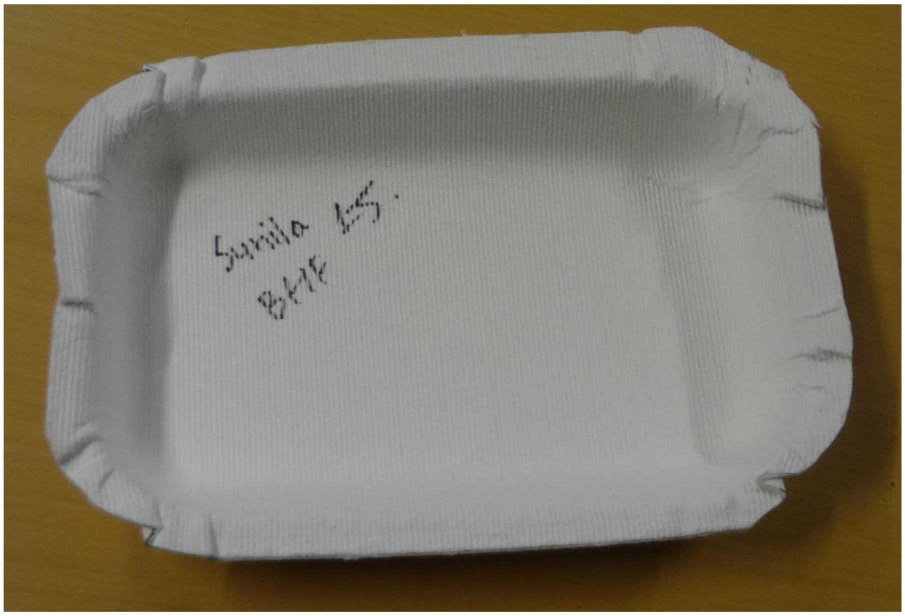


Picture 7. Ruptures in sample CTMP Research center with 15 % blank holding force

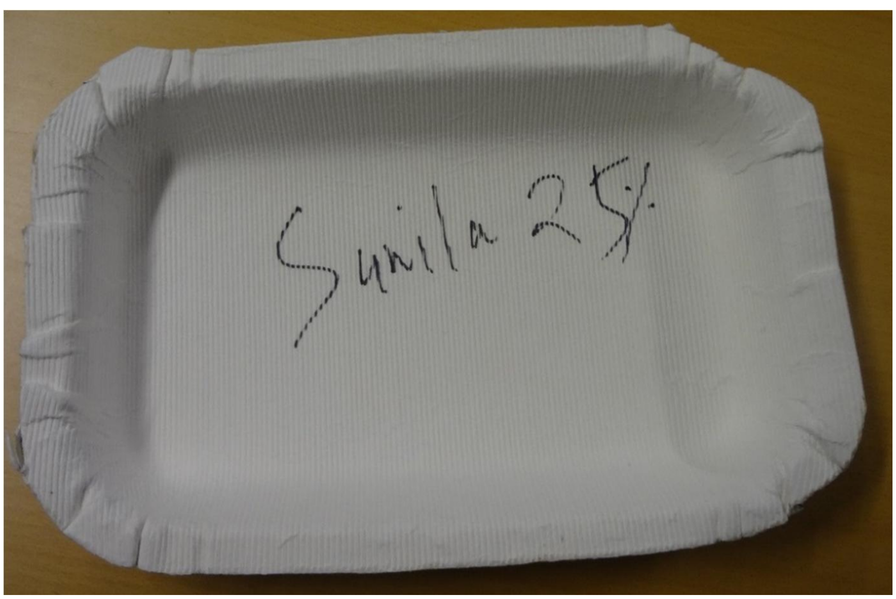
Picture 8. Ruptures in sample CTMP Research center with 15 % blank holding force.

Appendix 4

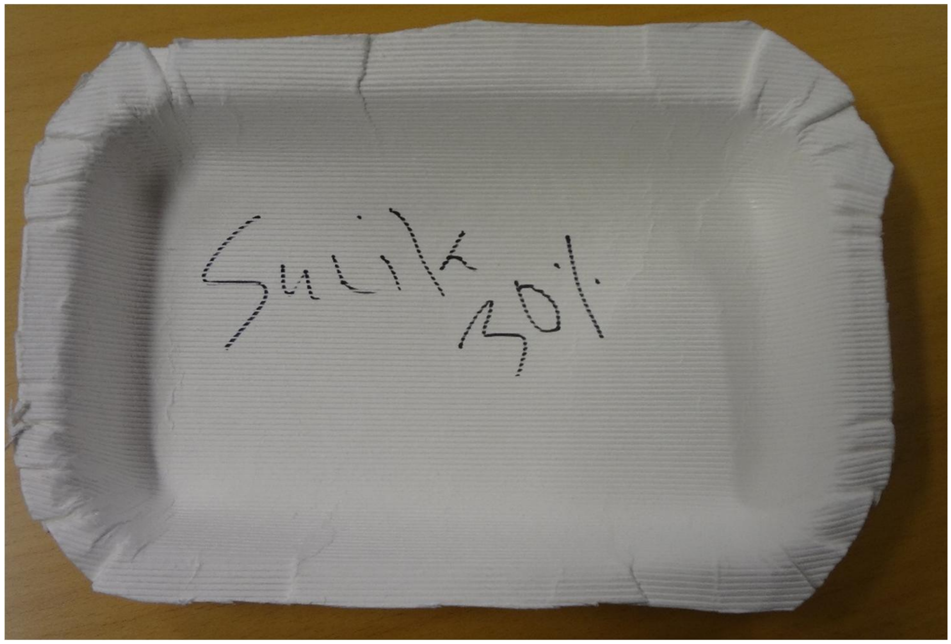
Sample nr 4 Sunila pulp



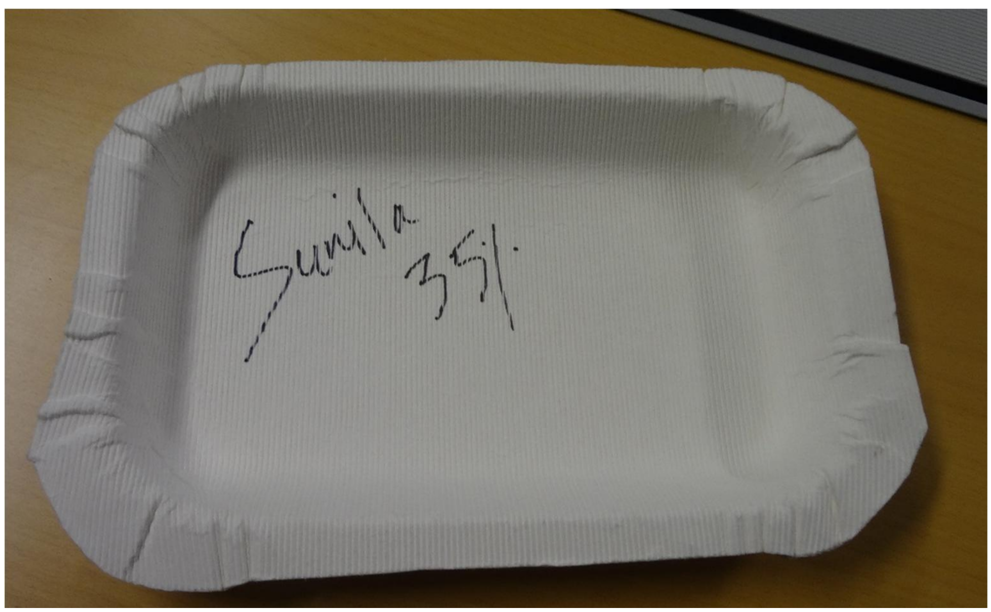
Picture 9. Sample of Sunila pulp with 15 % blank holding force



Picture 10. Sample of Sunila pulp with 25 % blank holding force



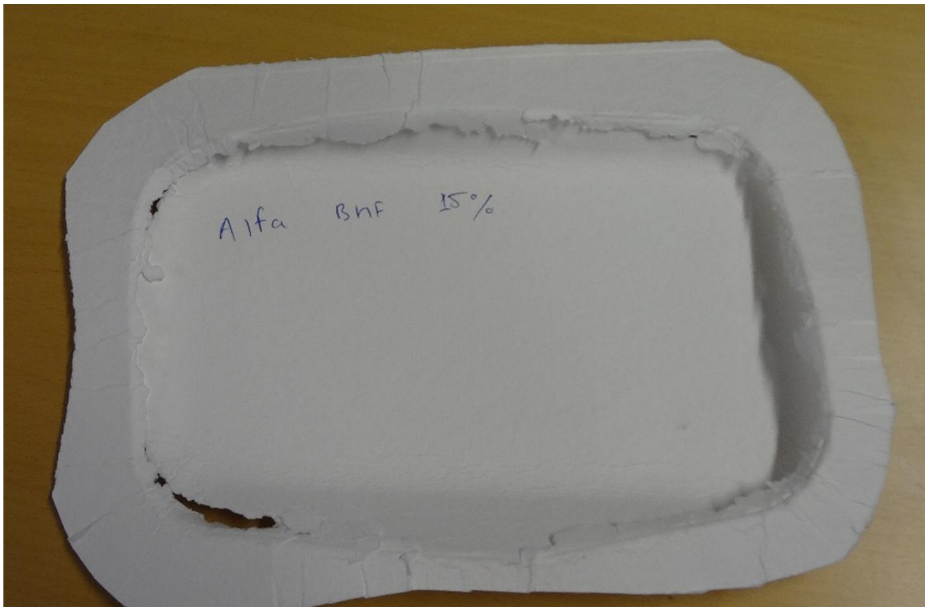
Picture 11. Sample of Sunila pulp with 30 % blank holding force



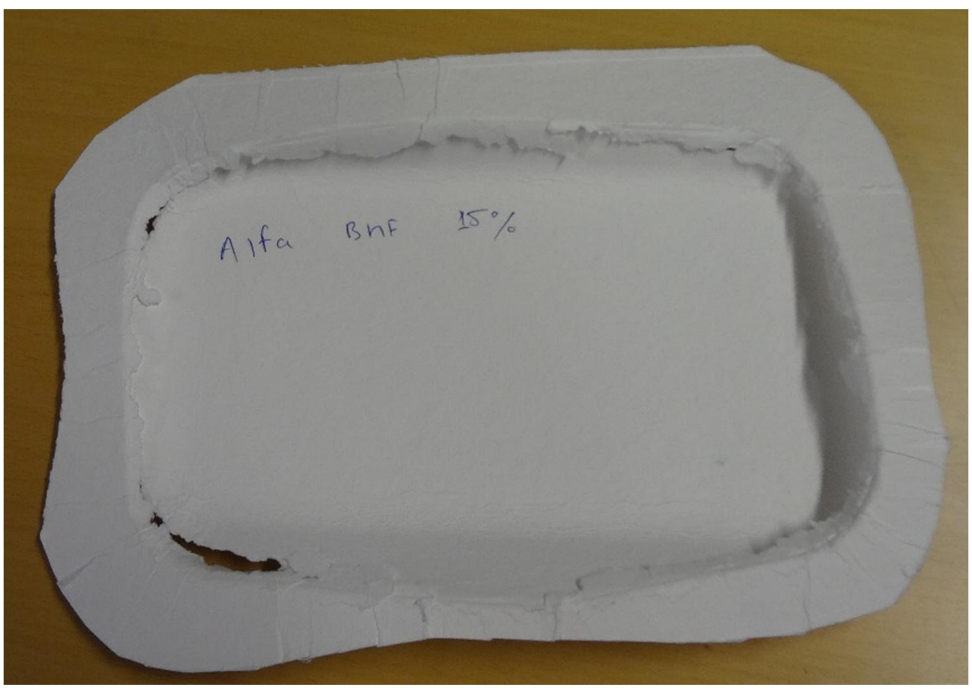
Picture 12 . Sample of Sunila pulp with 35 % blank holding force

Appendix 5

Sample nr 5 Eno Alfa



Picture 13. Ruptures in sample Eno Alfa pulp with 15 % blank holding force



Picture 14. Ruptures in Sample Alfa with 15 % blank holding force

Appendix 6

Sample nr 6 Enoforte EC-600

Picture 15 .Ruptures in sample Enoforte with 15 % blank holding force

Picture 16. Ruptures in sample Enoforte with 15 % blank holding force

Picture 17. Ruptures in sample Enoforte pulp with 25 % blank holding force

Picture 18. Ruptures in sample Enoforte with 35 % blank holding force

Appendix 7

Sample nr 7. Enopine EC-100

Picture 19. Sample of Enopine pulp with 15 % blank holding force.

Picture 20. Ruptures in sample of Enopine pulp with 20 % blank holding force.

Picture 21. Rupture in sample Enopine with 25 % blank holding force.

Picture 22 .Ruptures in sample Enopine with 35 % blank holding force.

Appendix 8

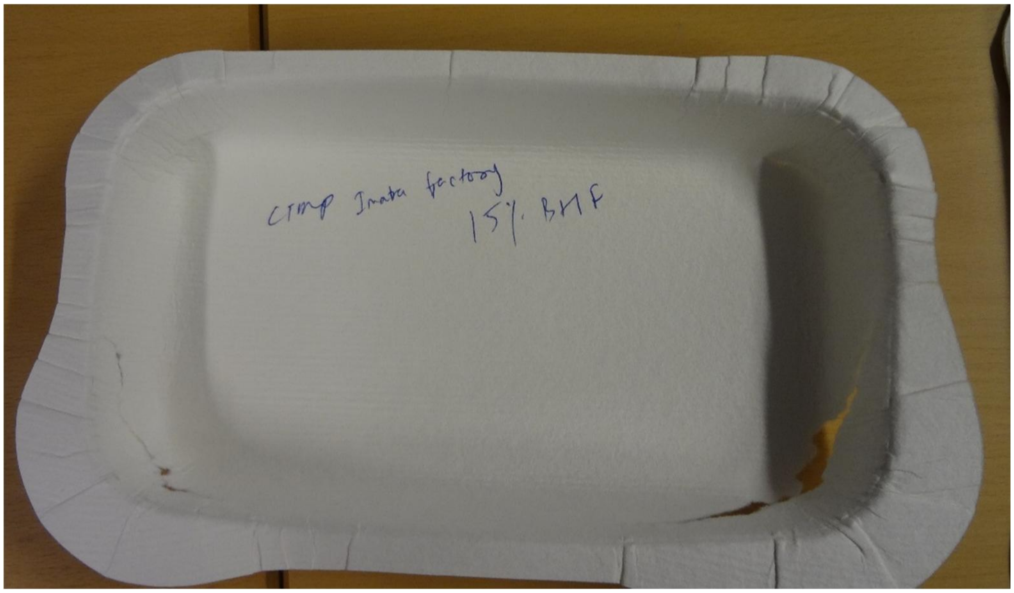
Sample nr 8 Koivu Imatra (birch)

Picture 23. Ruptures in sample Koivu Imatra with 15 % blank holding force.

Picture 24. Ruptures in sample Koivu Imatra with 35 % blank holding force.

Appendix 9

Sample nr 9 CTMP Imatra



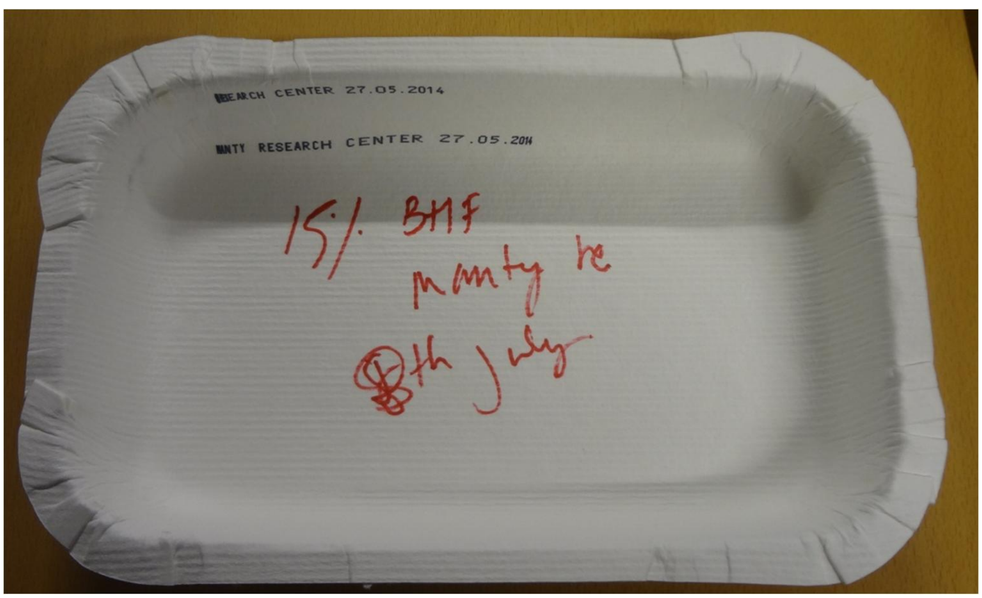
Picture 25. Ruptures in sample CTMP Imatra with 15 % blank holding force

Picture 26. Rupture in sample CTMP Imatra with 15 % blank holding force

Appendix 11

Sample nr1 Manty

Picture 27. Ruptures in sample Conditioned Manty pulp with 20% blank holding force.



Picture 28. Rupture in sample Conditioned Manty with 15% blank holding force.

Appendix 12

Sample nr2 Koivu Research Pulp

Picture 29. Ruptures in sample Conditioned Koivu Research pulp with 15% blank holding force.

Picture 30. Ruptures in sample Conditioned Koivu Research 15 % blank holding force.

Appendix 13

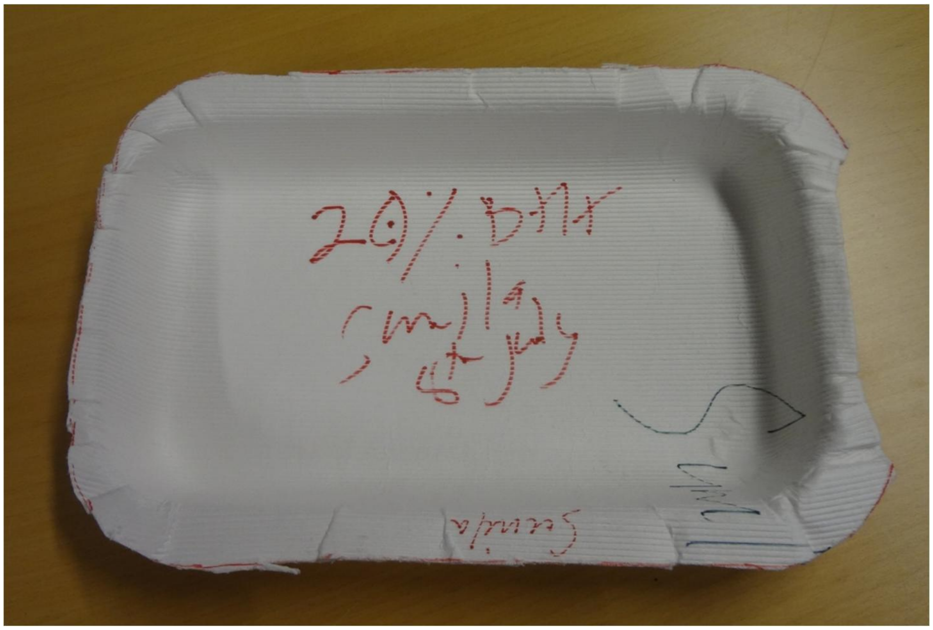
Sample nr3 CTMP Research Pulp

Picture 31. Ruptures in sample Conditioned CTMP Research with 20% blank holding force.

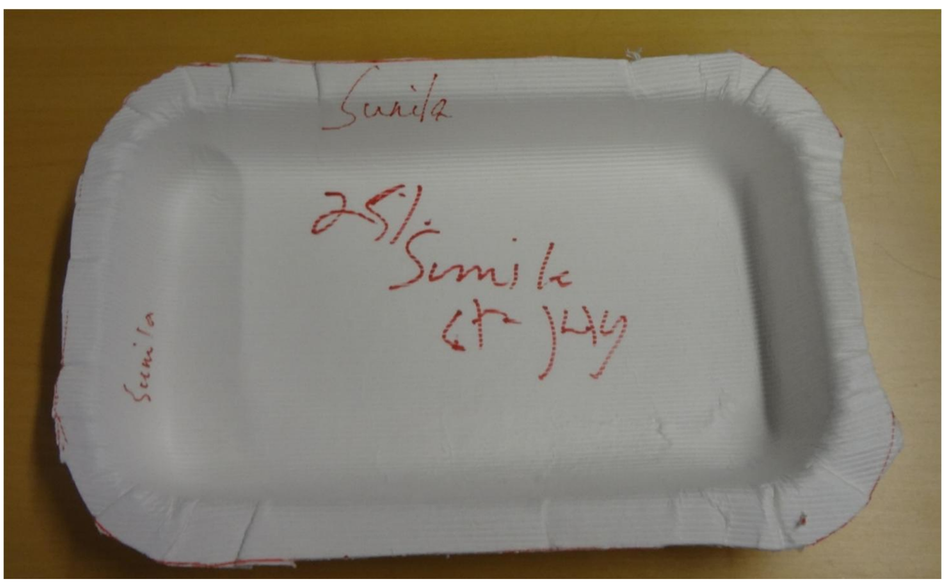
Picture 32. Ruptures in sample Conditioned CTMP Research with 20% blank holding force.

Appendix 14

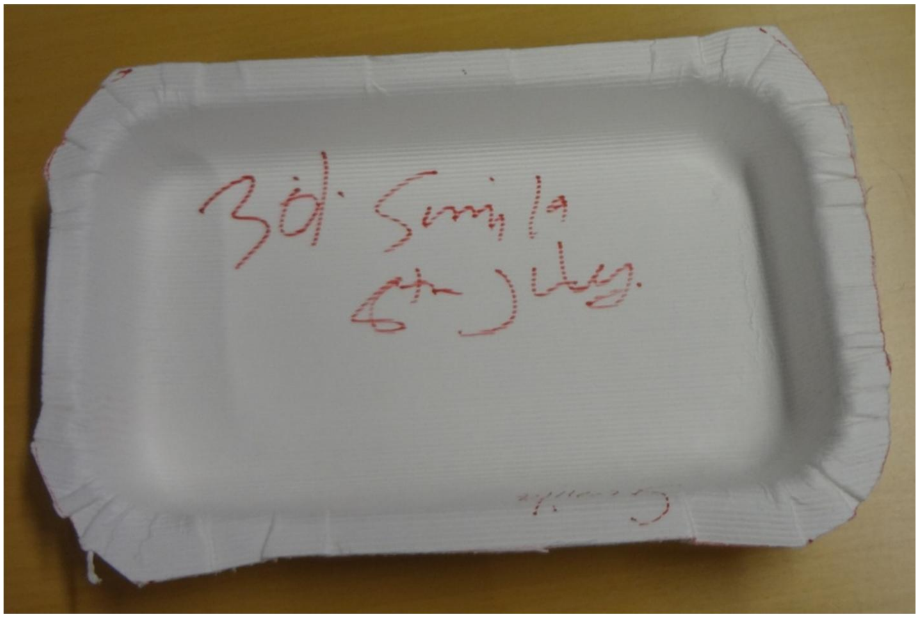
Sample nr 4 Sunila Pulp



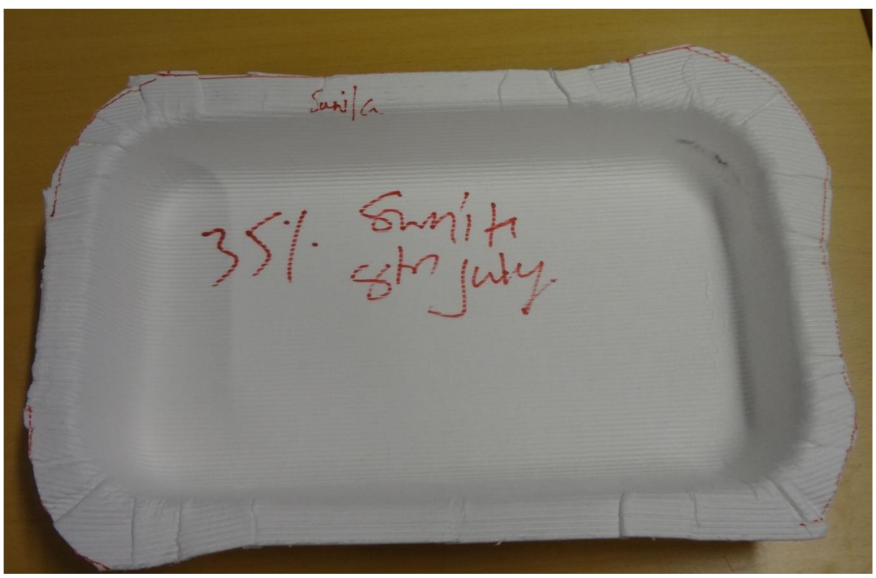
Picture 33. Ruptures in sample Conditioned Sunila with 20% blank holding force.



Picture 34. Ruptures in sample Conditioned Sunila with 25% blank holding force.



Picture 35. Ruptures in sample Conditioned Sunila with 30% blank holding force.



Picture 36. Ruptures sample in Conditioned Sunila with 35% blank holding force.

Appendix 15

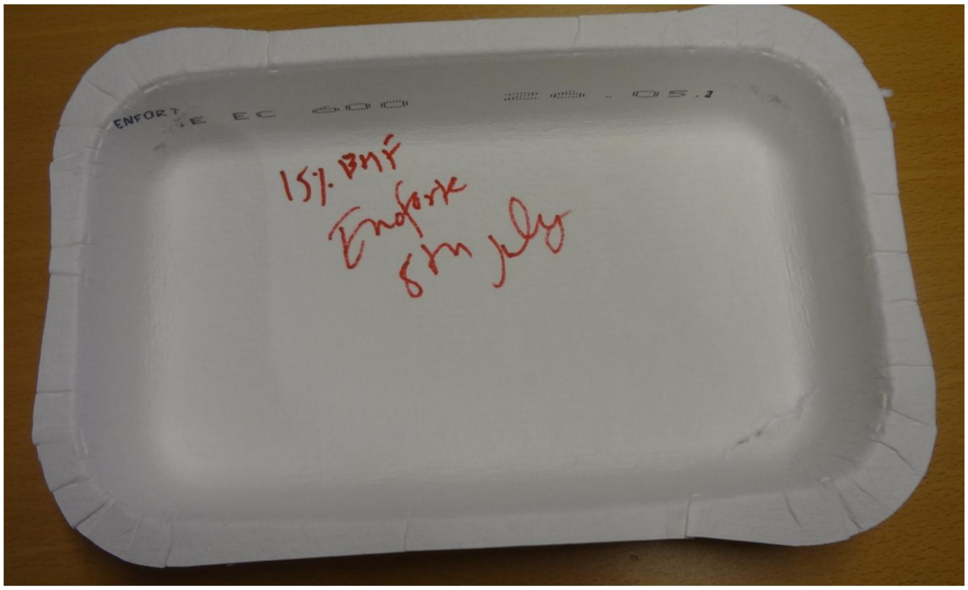
Sample nr5 Eno Alfa Pulp

Picture 37. Ruptures in sample Conditioned Eno Alfa with 35% blank holding force.

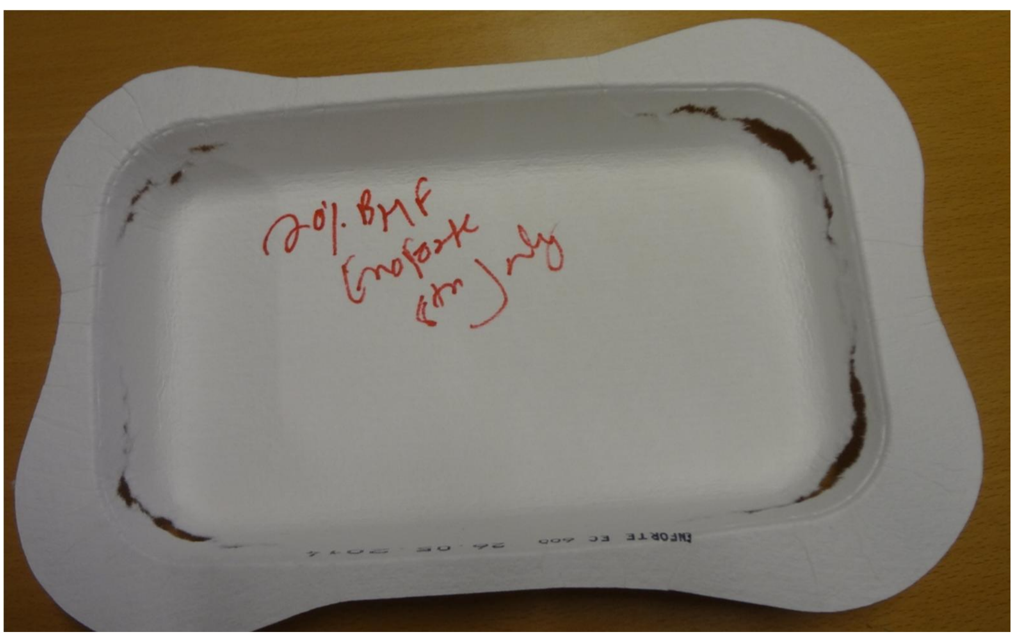
Picture 38. Ruptures in sample Conditioned Eno Alfa with 15% blank holding force.

Appendix 16

Sample nr6 Enoforte Pulp



Picture 39. Ruptures in sample Conditioned Enoforte with 15% blank holding force.



Picture 40. Ruptures in sample Conditioned Enoforte with 15% blank holding force.

Appendix 17

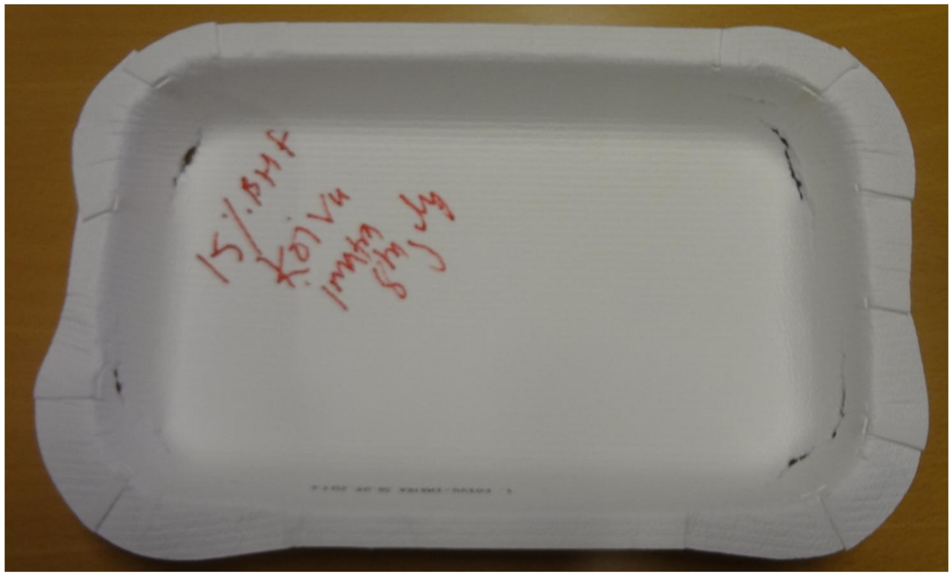
Sample nr 7 Enopine Pulp

Picture 41. Ruptures in sample Conditioned Enopine with 15% blank holding force.

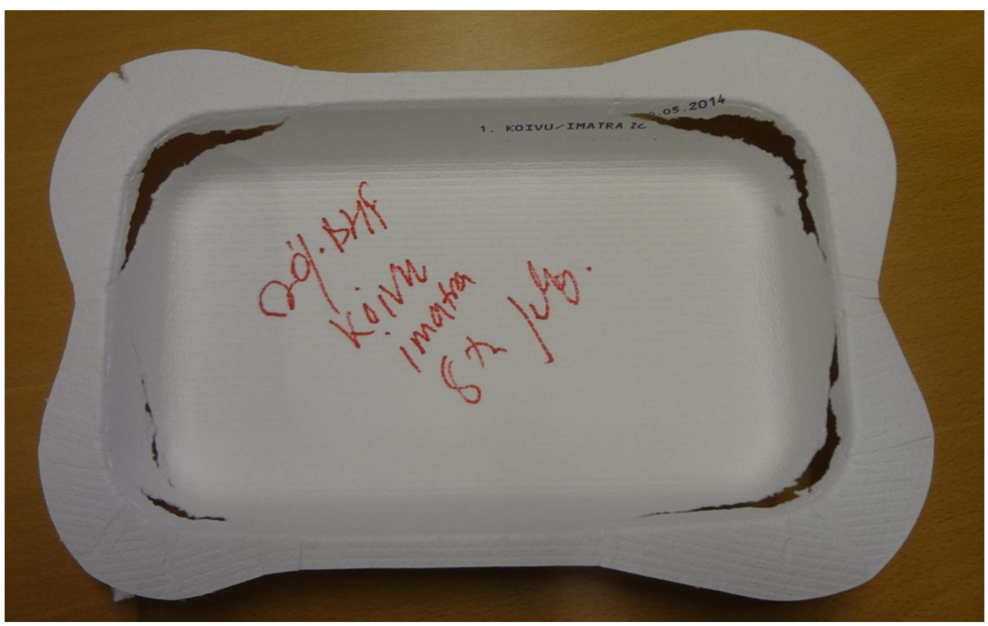
Picture 42. Ruptures in sample Conditioned Enopine with 20% blank holding force.

Appendix 18

Sample nr 8 Koivu Imatra Pulp



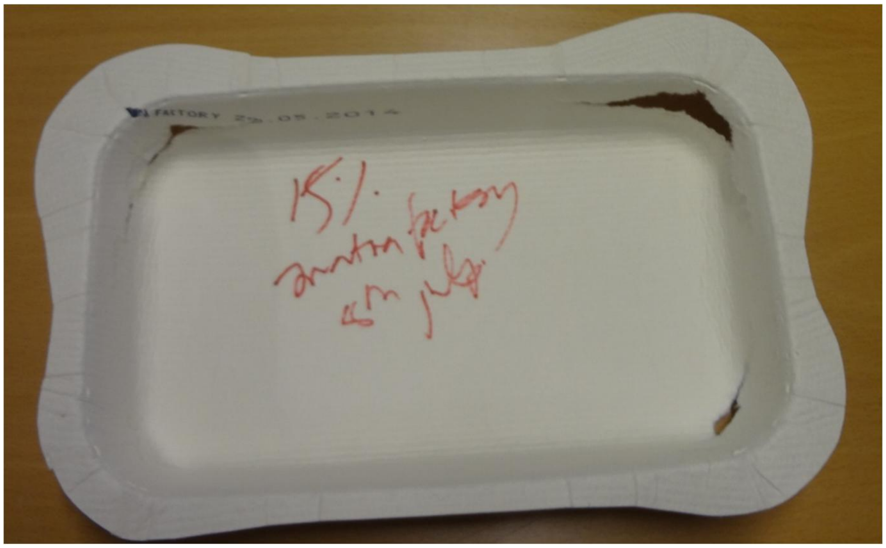
Picture 43. Ruptures in sample Conditioned Koivu Imatra with 15% blank holding force.



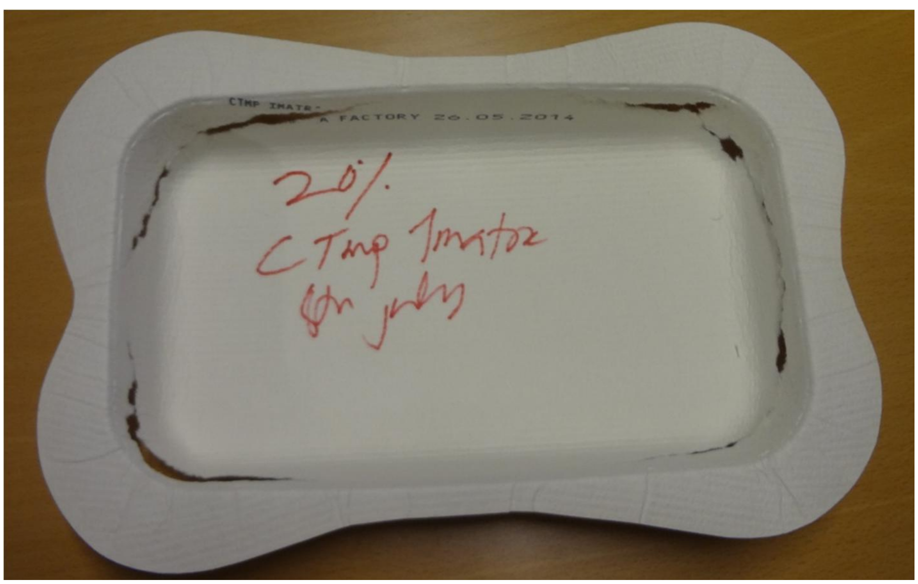
Picture 44. Ruptures in sample Conditioned Koivu Imatra with 15% blank holding force.

Appendix 19.

Sample nr 9 CTMP Imatra Pulp



Picture 45. Ruptures in sample Conditioned CTMP Imatra with 15% blank holding force.



Picture 46. Ruptures in sample Conditioned CTMP Imatra with 15% blank holding force.