Saimaa University of Applied Sciences
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Petri Penttinen

THE REFERENCE MEASUREMENTS OF THE PAPER LABORATORY

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ABSTRACT

Petri Penttinen
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Supervisor: Lecturer Esko Lahdenperä

The purpose of this bachelor's thesis was to create a basis for reference measurements of papers and boards used in the paper laboratory of Saimaa University of Applied Sciences in Imatra. Testing was focused to the most common physical properties of paper and board. The aim for the reference measurements was to setup a database of product properties. This database is later used as reference material when new properties of other products are measured.

In the theory part of the work is introduced the laboratory environment, quality systems, and the physical properties of the papers and boards that are measured. Also the test methods of these properties are explained. As the reliability of the testing is very important, in this work is also thought about the things that may cause uncertainty and errors to the results.

In the experimental part of the work is performed the basic- and strength properties of the specific papers and boards that were selected. The samples used consist of the paper and board grades manufactured in Stora Enso Imatra and M-real Simpele mills, and of the own samples made of birch, eucalyptus, pine and spruce pulps. These industrial manufactured paper and board types are commonly used with the student works and they can be found from the paper laboratory. Pulps for the own samples are from Stora Enso Imatra mills and they can also be found from the school´s paper laboratory.

Reference measurements were performed by the instructions of ISO standards and tests were carried out carefully to eliminate false results. Excessive deviation was avoided by selecting representative samples and repeating measurement enough time.

The quality of industrial papers and boards is very high as it came out also from the paper and board samples used in this work. With the own samples, deviation occurs much more and to get reliable enough results for the reference values, it demands carefully done sheets and more test repetitions. Commonly, it can be said that finding the reliable values for true average and true deviation, it demands lot of test repetitions.

Keywords: Reference, testing, quality, measurement, properties.

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Petri Penttinen
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Ohjaaja: Lehtori Esko Lahdenperä

Opinnäytetyön tarkoituksena oli suorittaa referenssimittauksia niistä paperi- ja kartonkilaaduista, joita käytetään Saimaan ammattikorkeakoulun paperilaboratoriossa Imatralla. Testaukset keskittyivät yleisimpiin paperin ja kartongin fyysisiin ominaisuuksiin. Referenssimittauksilla rakennetaan eri tuotteiden paperiteknisistä ominaisuuksista tietokanta, johon jatkossa voidaan vertailla toisia tuotteita.

Työn teoriaosassa käydään läpi laboratorio työympäristönä, laadunhallinta-järjestelmät sekä paperin ja kartongin fyysiset ominaisuudet, joita tässä työssä testataan. Myös testausmenetelmät näiden ominaisuuksuuksien mittaamiseen on selitetty. Tulosten luotettavuudella on suuri merkitys laadunvalvonnassa ja tässä työssä selvitetään myös seikat, jotka voivat aiheuttaa virheitä ja poikkemia tuloksiin.

Työn kokeellisessa osassa suoritettiin näytteiksi valikoitujen paperien ja kartonkien yleisimmät perus- ja lujuus-ominaisuudet. Näytteet koostuvat teollisesti valmistetuista paperi- ja kartonkilajeista sekä omista koivu-, eukalyptus-, mänty- ja kuusiarkeista. Teollisesti valmistetut paperi- ja kartonkinäytteet ovat Stora Enso Imatran ja M-real Simpeleen tehtailta ja sellut omiin arkkeihin ovat Stora Enso Imatran tehtailta. Nämä paperi-, kartonki- ja sellunäytteet löytyvät koulun paperilaboratoriosta ja ovat yleisesti käytössä oppilastöissä.

Referenssimittaukset suoritettiin ISO standardien ohjeiden mukaan ja mittauksissa kiinnitettiin erityistä huomiota huolellisuuteen, tarkkuuteen ja oikeaan suoritustekniikkaan. Liiallinen hajonta pyrittiin välttämään valitsemalla edustavat näytteet ja toistamalla mittaus tarpeeksi monta kertaa.

Kuten tässäkin työssä saaduista tuloksista käy ilmi, teollisesti valmistettujen paperien ja kartonkien laatu on korkea ja tasainen. Omilla arkeilla ilmenee huomattavasti enemmän hajontaa ja se tulisi ottaa huomioon testausta suoritettaessa. Yleisesti voidaan sanoa, että saadakseen selville jonkin paperi- tai kartonkilajin ominaisuuden todellinen keskiarvo ja keskihajonta, tarvitaan riittävä määrä mittauksia.

Avainsanat: Referenssi, testaus, laatu, mittaus, ominaisuudet.

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1 PREFACE

Testing the properties of manufactured products is a common feature of all industrial operations. This is also the case in the pulp and paper industry. Paper is a material built up from individual fibers, fillers, additives and other components. The properties of the paper depend both on the properties of these components and on the interactions between them.

Testing and analytical procedures are needed to describe the properties of single fibers, the fiber collective in the form of fiber suspensions, and the fiber collective in the form of the final network – the paper. More or less direct testing and analytical methods have already been developed.

The aim for this thesis work was to perform the most common tests of physical properties of certain paper and board grades that are used and can be found in the paper laboratory of Saimaa University of Applied Sciences in Imatra. The tests are selected from the most common basic and strength properties of paper and board. The samples consist of the industrial manufactured papers and boards from Stora Enso Imatra and M-real Simpele mills, and of the own eucalyptus-, birch-, pine- and spruce sheets made of the pulps from the Stora Enso Kaukopää mill, Imatra.

In the literature part are presented the testing environment and the properties of the paper and board that are tested in this work. Also the principles of the testing procedures are briefly explained as well as the things affecting to reliability of the results.

In the experimental part of work, the reference measurements of the selected basic and physical properties are measured by the instructions of the ISO standards. The samples are conditioned at the standardized atmosphere and tests are performed carefully so that the test results should give as accurate information as possible and that they could be used as reference values in the future.

2 PULP AND PAPER TESTING

Testing has always been important part in industrial processes. Testing is used to control process conditions and the quality of the final product. As industrial processes become more sophisticated and tolerances for products become tighter, the importance of efficient and relevant testing has increased. (Levlin & Söderhjelm 1999)

Testing tries to describe numerically certain relevant properties or features of the product, its intermediates, or both. When testing technical products using physical or chemical methods, it is not always certain that a specific test measures exactly the feature of the product of interest. A relevant test measures a parameter that correlates well with the property of the product under consideration. (Levlin & Söderhjelm 1999; Holik, H. 2006)

Depending on the purpose, testing may use intermediates or final products to control process conditions or the intent may be quality control of the final product with relevant quality specifications. Testing may also try to obtain property values for use in marketing a product. In all these cases, the selection of tests for each product may be different and it requires proper consideration before starting testing programs. (Levlin & Söderhjelm 1999; Holik, H. 2006)

Nowadays, a lot of testing is done directly on-line during the production process. On-line measurements make the process easier to control and more efficient, and they help to control the quality of the product. Therefore, on-line testing is used in industry as much as possible. (Levlin & Söderhjelm 1999)

Despite increasing on-line testing, traditional laboratory testing is needed and it will most likely always remain. Some of the necessary tests can not be done on-line. On-line testing equipment also requires calibration with laboratory tests. Another important thing is, that the samples are conditioned in standardized atmosphere in laboratory which can not be achieved with on-line testing. A customer may also require very specific tests that can be only done with laboratory tests. (Levlin & Söderhjelm 1999; Holik, H. 2006)

In order to have successful testing program, it is important to choose the proper selection of relevant analyses and tests for raw materials, intermediates, or final products. The identification and establishment of tests and analyses must be based on relevant process and product analysis. Process conditions and variations should be considered as well as the feature or function of the material or product that the analysis describe. (Levlin & Söderhjelm 1999; Holik, H. 2006)

2.1 Process analysis

Process analysis tries to define the control variables of the process that allow it to run smoothly and produce products with the necessary properties. It uses existing experience and knowledge about the process behavior. (Levlin & Söderhjelm 1999)

The first step in process analysis is to define the critical control variables, that enable the achievement of desired product properties. If an important product or process property changes positively while another changes negatively due to change in a control variable of the manufacturing process, the variable is a critical control variable. The properties concerned form a critical pair of properties of a paper. An example of this is influence of the amount of beating on properties of a paper. The tensile strength increases, but the opacity decreases. If the tensile strength and opacity are important properties of the paper, the amount of beating is then a critical control variable. In this case, tensile strength and opacity are product properties requiring measurement to control the beating process. (Levlin & Söderhjelm 1999)

Process analysis can involve building a matrix where each horizontal line represents the influence of a control variable on a number of different process variables or product properties. This allows easy definition of control variables influencing important properties in opposite directions. (Levlin & Söderhjelm 1999)

2.2 Product analysis

The aim of product analysis is to define the properties that relate to use of a specific product or material. Product analysis defines the important features and requirements concerning the functional behavior or use the product. It also defines the measurements that can provide numerical information of relevance to this behavior. (Levlin & Söderhjelm 1999)

Product analysis can be seen as building a matrix where the horizontal lines represent different functional requirements related to the product. The columns describe different measurable properties. Properly completing matrix gives a good overview of the relationships between the different functional requirements and measurable properties of the product. This is also the approach to apply when selecting tests to use for product development, to describe the end-use potential of a product, or both. (Levlin & Söderhjelm 1999)

3 THE PAPER AND BOARD TESTING LABORATORY

Before the testing equipment was developed, paper was simply made to match a previous accepted sample. Quality of paper was measured with human senses of sight and touch. These were the first test instruments. Visual perception was used to evaluate the properties of color, formation, opacity and brightness. Sense of touch was used to determine the smoothness, thickness, burst and tearing strength. To some degree human senses are still used but they are influenced by the physiological and psychological factors of the person evaluating the paper. Undoubtedly it is rather impossible to completely eliminate human interventions. Test instruments qualify or quantify numerically a property of paper and board, and they give unbiased results with minimized human errors. (Borch, Lyne, Mark, Habeger 2002, p.2-3)

3.1 Laboratory types

Paper and board testing laboratories can be classified into research, mill, customer, and academic laboratories.

3.1.1 Research laboratories

Research laboratories have the capability to test any product manufactured by their company and its competitors. The wider the range of the company´s products, the greater the need for more varied equipment. Thus, besides testing products, development and investigation of new test instruments is another important duty of research laboratory. Researching and developing can result in increased productivity and help to further improve the quality of product by getting more accurate definition to its properties. The aim for such laboratories is also to predict new methods for improving existing products and to work as a tool for problem solving. (Borch etc 2002, p.3)

3.1.2 Mill laboratories

The production is being monitored in mill laboratories. With these tests it is assured that the quality of the product meets the requirements of the customer and can be shipped out. There are opinion differences whether mill laboratories are anymore needed because highly developed on-line testing, but in the meantime these laboratories continue to ensure that the specifications are met. (Borch etc 2002, p.4)

3.1.3 Customer laboratories

The customer wants to know how the product performs. The testing is done for ensuring that product specifications are met. Realistically, customer laboratories are not interested in how the paper or board was made, they are concerned about the quality of product. (Borch etc 2002, p.4)

3.1.4 Academic laboratories

Academic laboratories are instrumental in proving or disproving the existing and/or proposed principles and theories of the physical characteristics of paper and board. The academic laboratory may also be called upon as a neutral party to help solve a problem that is either common to the industry or confined to a single company. New test instruments have been researched thoroughly for the industry in such laboratories. (Borch etc 2002, p.4)

3.2 Outside influences

It is important to consider the outside factors that could adversely affect the test result performed in the testing laboratory. Vibration is major factor distorting test results. Testing instruments are calibrated in constant vibration and they don´t give reliable results when this state is distorted by unspecific vibration. Drifting can often be attributed to excessive vibration in the laboratory. Damping elements are usually suggested to reduce or eliminate the problem. These elements include multilayered fiber-impregenated pads, leveling feet mounted on sponge rubber, and balance tables made of marble slabs to diminish floor vibrations. (Borch etc 2002, p.4)

Disturbance in the electric stability may cause spikes, interruptions and brownouts to electric current feeding, all of which can affect the calibration of an instrument. This problem can be fixed by installing a line stabilizer to eliminate the possibility of adverse electrical influence. (Borch etc 2002, p.4)

Those instruments that require the use of water or air may lead to unreliably test results, if the water and/or air used is not clean and contains any type of contaminants and impurities. Filters that are placed strategically correct, reduce remarkably impurities of the water. Filters should be used and replaced regularly at scheduled intervals. Contaminants occur always at all locations, including research centers and universities. No matter how clean the air supply is supposed to be, a power failure, mechanical breakdown in the laboratory controls, or repair on the building`s main air lines will introduce some or all of the contaminants present in a mill or plant atmosphere. (Borch etc 2002, p.4-5)

3.3 Inside influences

The quality of testing is affected by the location of the laboratory. For example if the laboratory is in a paper mill and located very near the machine, it obviously doesn´t provide the same circumstances than a stand-alone laboratory away from the machine floor. If the quality of testing is indeed paramount, it is important to know those parameters that have influence on testing conditions and be able to control them anyhow possible. (Borch etc 2002, p.5)

Even slight changes in temperature and humidity can often affect the test results. For example, an increase in temperature without an increase in humidity increase tensile and burst characteristics. An increase in humidity can change tear strength and even optical parameters such as gloss. The main thing is to control temperature and humidity even in the most adverse conditions, so that the precision and accuracy required in the production of quality testing is achieved. Testing atmosphere should be maintained within the standardized conditions of 23 ± 1 ℃; 50 ± 2 %. Conditioned test atmosphere is explained more carefully in chapter 6.5. (Borch etc 2002, p.5)

4 STANDARDIZATION IN PULP AND PAPER TESTING

A standard is a way to define the properties of a product of the performance of an action. Examples are quality, safety, dimensions, testing procedures, packaging of a product, manufacturing process, terminology, or symbols. Interested parties should prepare a standard together so that it includes the interests of all concerned. The standard should use scientific or technical evidence or experience. Standards are used in all segments of society in purchasing, manufacturing, consumer life and environmental protection. The aim of standardization is:

- Simplification by reducing the number of alternative procedures or products
- Making communication easier by ensuring common understanding and expression such as units and terminology
- Promoting international trade by eliminating trade barriers originating from different engineering specifications
- Ensuring safety in society such as standards for occupational health and safety
- Protection of the consumer such as standards on quality requirements for certain products
- Supporting legislation such as standards for test methods for environmental surveys (Levlin & Söderhjelm 1999, p.269)

Two main groups of standards are available: official and industrial branch standards. A public body such as a nation or group of nations recognizes official standards. ISO (worldwide), EN (Western Europe), ASTM (United States), and national standardizing organizations develop official standards. Branch standards that are not always created with all the targets expressed above are published by SCAN-test (the paper industry in Nordic countries) and TAPPI in the United States of America. Although these standards do not have official recognition and do not have all the properties characteristic of official standards, they are significant to the paper industry. Standards are used in all segments of society in purchasing, manufacturing, consumer life and environmental protection. (Levlin & Söderhjelm 1999, p.270)

For pulp, paper and board, the most important world-wide standards for testing were created in the 1960s and 1970s. Efforts today primarily involve revision of standards resulting from the rapid technical progress in manufacturing and testing of products. Pulp and paper standards usually relate to testing procedures and the number of product standards is very low in this industry. (Levlin & Söderhjelm 1999, p.270)

4.1 ISO standards

The international Organization for Standardization (ISO) is the world's largest developer and publisher of International Standards, at present (2011) comprising 159 members, one in each of 159 countries. Their mission is to promote the development of standardization and related activities in the world to facilitate international exchange of goods and services and develop cooperation in intellectual, scientific, technological, and economic activity. International standards are the publications for work of ISO. (Borch 2002, p.7; Levlin & Söderhjelm 1999, p.270)

The scope of ISO covers standardization in all fields of life except electrical and engineering standards. These are the responsibility of the International Electrotechnical Commission (IEC). Work in the field of information technology is carried out by a joint ISO/IEC technical committee. (Levlin & Söderhjelm 1999, p.270)

ISO/TC 6 “Paper, board and pulps” created in 1947 (the founding year of ISO) prepares standards for products in the pulp and paper industry. Standardization includes terminology, sampling procedures, test methods, product and quality specifications, and the establishment and maintenance of appropriate calibration systems. The concentration of ISO/TC 6 is on test methods. To date, the group has 33 member countries and it has published 177 International Standards. (Levlin & Söderhjelm 1999, p.271)

4.2 CEN standards

The European Committee for Standardization (CEN) is a business facilitator in Europe, removing trade barriers for European industry and consumers. Its mission is to foster the European economy in global trading, the welfare of European citizens and the environment. Through its services it provides a platform for the development of European Standards and other technical specifications. CEN was founded in 1961 and it has 31 member countries. Close cooperation exists with the European Union (EU) and the European Free Trade Association (EFTA) since some CEN work relates to legislative harmonization. (Levlin & Söderhjelm 1999, p.271)

CEN/TC 172 “Pulp, paper and board” created in 1989 prepares EN standards in pulp, paper and board. The scope of TC 172 is standardization of nomenclature, test methods and specifications. This applies to raw materials, pulp, auxiliary materials for paper and board manufacture, paper and board, and some products consisting primarily of pulp, paper and board. (Levlin & Söderhjelm 1999, p.271)

While ISO/TC 6 has concentrated its efforts on testing procedures, CEN/TC 172 has also devised specifications. For example, a standard specifies the most important properties of copy paper and a trade list specifies 51 grades of recovered paper. By March 2011 there were available 70 EN standards developed by CEN/TC 172. Many of those are ISO standards adopted by CEN. EN publication is in English, French and German. (Levlin & Söderhjelm 1999, p.273; http://www.cen.eu)

4.3 Industrial branch standards

Technical corporations in some countries issue so-called “standards”. These are not standards in the strict sense since they have no official recognition. National standardization bodies may eventually adopt them as national standards. The unofficial standards primarily concern test methods. The most common series in the pulp and paper industry are the test methods published by SCAN-test and TAPPI. (Levlin 1999, p.274)

4.3.1 SCAN-test

The central laboratories of the pulp, paper and board industries in Finland, Norway and Sweden issue and recommend the SCAN-test standards. Since 1961, SCAN-test has published more than 200 test methods. They cover a larger field compared to ISO since they also include test methods applied in manufacture of pulp and paper. The SCAN-test methods are available in English, Finnish and Swedish. They comprise test methods for chemical and mechanical pulp, paper and board, nonfibrous materials, tall oil and turpentine oil, and waste water. Methods of a more general nature are also available. The SCAN-test methods are highly professional since committees representing the best analytical expertise prepare them with scrutiny at several levels before publishing, intercalibration among several levels before publishing, intercalibration among several laboratories is necessary before publishing the methods. (Levlin & Söderhjelm 1999, p.274)

4.3.2 TAPPI

TAPPI publishes an even larger series of test methods. The total number of test methods exceeds 400. They are official, provisional and classical methods covering testing of fibrous materials, pulp, paper, and paperboard, nonfibrous material, containers, and structural materials. TAPPI test methods are common globally. (Levlin & Söderhjelm 1999, p.274)

5 INTERLABORATORY REFERENCE SYSTEMS

In 1969, The National Bureau of Standards (now designated the National Institute of Standards and Technology) and the Technical Association of the Pulp and Paper industry (TAPPI) developed an interlaboratory program for paper and paperboard testing. Since 1971, Collaborative Testing Services (CTS) has operated the Collaborative Reference Program for Paper and Paperboard with technical guidance from TAPPI. Both the process and Product Quality and Container Board divisions of TAPPI support a Collaborative Testing standing committee whose function is to oversee the programs expansion and to make general recommendations concerning the program. (Borch etc 2002, p.10)

With more than 400 organizations around the world participating in these tests, this program has become one of the largest of its kind. This allows laboratories to compare the performance of their testing with that of other participating laboratories and provides a realistic picture of the state of paper testing for TAPPI. The global program is designed to demonstrate real-world lab performance and to assist the participating members in achieving and maintaining quality assurance objectives. (Borch etc 2002, p.10)

In Europe, the interlaboratory reference system is that of the European Confederation of Pulp, Paper and Board Industries (CEPAC). Recognized institutions in England, France, Germany, Italy and the Netherlands serve as coordinating laboratories. Each location is responsible for determining the provisional values on samples for specific test methods. The samples are then distributed to the participants. Analyses and reports are issued. Similar systems are in effect elsewhere within in the paper and board testing community. (Borch etc 2002, p.10)

An interlaboratory reference program provides documentation of abilities to test accurately in comparison with the other participants in the program. The information can help assure manufacturing divisions, suppliers and clients of the capabilities in maintaining an efficient testing laboratory. As with any worthwhile endeavor, the success of this type of program is dependent upon everyone involved, as its name implies. (Borch etc 2002, p.10-11)

6 RELIABILITY OF RESULTS IN PULP AND PAPER TESTING

Pulp and paper are not homogenous materials. In pulp and paper testing, the measurement is often repeated several times to determine an average result that describes the level of the property better than single measurements. A statistical distribution always relates to the test result. The size and type of distribution depend not only on the homogeneity of the material and the number of repetitions of the test but also on other factors such as equipment and operator. This distribution should always be known for proper use of the test result. (Levlin & Söderhjelm 1999, p.257, Jaarinen, S. & Niiranen, J. 2005)

6.1 Precise and accurate data

Uncertainty of a measurement is a parameter associated with the result of a measurement that characterizes the dispersion of the values reasonably attributed to the measurand. The measurand is a particular quantity subject to measurement. (Levlin & Söderhjelm 1999, p.258, Jaarinen, S. & Niiranen, J. 2005)

The uncertainty of a results of measurements is the closeness of agreement between results of successive measurements using the same material under the same conditions. This means the same material under the same conditions. The same operator repeats the measurements within a short period of time without any changes in measurement procedure, equipment, or test conditions. Any variation noted this way describes the repeatability of the measurement. (Levlin & Söderhjelm 1999, p.258, Jaarinen, S. & Niiranen, J. 2005)

Precision deals primarily with the instrument in use and its ability to reproduce test results over and over again. It is defined as the agreement between numerical values of two or more measurements that have been made in an identical fashion. Data may be precise and reproducible but yet be very inaccurate because of methodology, technique, calibration or instrument differences. (Borch 2002, p.5)

Accuracy means the nearness of a measurement to its accepted value and involves a comparison to a true or accepted value. Accuracy can be achieved only if technique, calibration and methodology are all correct. It can be said that accuracy has the greatest contribution to successful testing. (Borch etc 2002, p.5-6)

Reproducibility of results of measurements is the closeness of the agreement between the results of measurements using different conditions of measurement. When defining reproducibility, any conditions can change including the principle of the method. Statements about reproducibility therefore require a specification of the conditions varied. Normally, people want to know the reproducibility of measurement within their own laboratories and between laboratories. (Levlin & Söderhjelm 1999, p.258-259, Jaarinen, S. & Niiranen, J. 2005)

Standards describe how repeatability and reproducibility tests should be done and the values calculated for a test method. When the repeatability and reproducibility of the test method are determined, the most homogenous materials are used for testing. This minimizes the effect of the material as much as possible. Repeatability and reproducibility are often given as % of the mean value of the test result concerned. (Levlin & Söderhjelm 1999, p.259)

6.2 Material and sampling

Fiber-based materials contain always variations. The variation is natural. Pulp, paper or board consist of individual fibers that differ in length, shape, chemical structure etc. The differences and variations of properties of fibers increase during pulping. The papermaking process itself also creates large variations in the structure and properties of paper. (Levlin & Söderhjelm 1999, p.262; Alen R. 2007)

The resulting paper has significant variations. Their scale varies from microscopic to macroscopic and in every direction. In many cases, the heterogeneity of the material is the main effect contributing to uncertainty of the results. (Levlin & Söderhjelm 1999, p.263; Alen R. 2007)

In most testing procedures, the test is repeated several times (usually 10 repetitions in standard methods for physical properties) to obtain a more precise estimate of the value for the property measured. This also minimizes the uncertainty contributed by material variability. (Levlin & Söderhjelm 1999, p.263)

Because considerable variation exists in the material, sampling is a difficult task in testing fiber-based materials. The purpose of the testing may be process control, comparison of product properties with specification, or research and development work. The intended use of test results determines how the sampling should be done. However, there are restrictions. Papermaking is a continuous process and sampling must not disturb it. Normally, one must be satisfied with only a few specimens representing many tons of pulp or paper. These specimens are the best representatives of the lot. This dilemma has created considerable pressure to develop on-line measurement techniques. (Levlin & Söderhjelm 1999, p.263)

The number of specimens taken to represent a lot and the number of test pieces taken from these specimens requires careful consideration. With many test pieces taken from specimens, the average of the test results is a good approximation of the average of the lot. With only a few test pieces from few specimens, the average depends highly on material variability. Standards describe procedures for sampling of testing materials from pulp, paper or board consignments and other lots. Sampling for process control requires individual consideration from process to process depending on the process and customer needs and restrictions made by the process. (Levlin & Söderhjelm 1999, p.263)

6.3 Test method

The principle of the measurement may have an effect on uncertainty. Different methods may be available to measure the same property of a material. In such cases both the average numeral value and precision of the measurement may vary even when testing the same material. (Levlin & Söderhjelm 1999, p.263)

Instructions about performing a test may not be sufficient strict. The repeatability and reproducibility of a test method are usually available in standards describing the test. Values are often the results of collaborative studies where the test is performed strictly according to the procedure in different laboratories using the same material. (Levlin & Söderhjelm 1999, p.263)

Another feature to be considered is that most physical tests performed on pulp and paper are destructive. The test damages the specimen, and repeating the test on the same test piece is impossible. For repeatability studies, specimens for replicates come from a small area of test paper to minimize the effect of material variations. (Levlin & Söderhjelm 1999, p.263)

6.4 Equipment

Performance of test equipment contributes always some uncertainty to results. The size of the effect depends for example on the condition, calibration, precision, stability, linearity, measuring range, sensitivity and resolution of the device and is specific to the equipment. Good maintenance and traceable calibration whenever possible are key elements to minimize uncertainty due to equipment. (Levlin & Söderhjelm 1999, p.264)

Traceable calibration means an unbroken chain of comparison from a working standard for the testing equipment to the international primary standard of the quantity concerned. Such chains exist for length, mass, time, force humidity and other basic quantities. Certified reference materials are also useful for calibration purposes. The reference value and uncertainty of the standard of reference material must be known and used for evaluation of combined uncertainty. (Levlin & Söderhjelm 1999, p.264)

In physical testing of pulp and paper, most equipment can only be partly calibrated to the basic quantities. A lack of certified reference materials exists because the fiber material itself if often too heterogeneous for calibration purposes. This causes problems when comparing equipment and evaluating uncertainty components. (Levlin & Söderhjelm 1999, p.264)

6.5 Test environment

Laboratories are specified to work at standardized atmosphere which is defined by The Technical Association of the Pulp and Paper Industry (TAPPI). Maintaining these conditions (23 ± 1 ℃; 50 ± 2 %) is by fa r the most exacting, trying, and frustrating requirement in an efficient, reliable test laboratory. In some cases, changes have to be made in the room´s system to stay within the required limits. The following are examples of changed situations. (Borch etc 2002, p.6)

- When manually operated equipment is updated to automated equipment and new instruments are added.
- When the number of technicians in the laboratory and/or the number of outside personnel using the laboratory facilities is changed.
- When renovation and/or expansion is done.

It is recommended that most paper samples should be exposed to the standard atmosphere for a minimum of 4 hours (5-8 for heavier papers) and up to 48 hours for boards. A further complication can arise, however, because the paper's natural moisture content may not be the same as the moisture content it will have after conditioning in the standard atmosphere. The test results obtained will depend on whether the natural moisture content was brought down to, or raised up to the moisture content after conditioning. This is known as a hysteresis effect. To minimize hysteresis effects, for the most accurate results, it is recommended that the samples are first preconditioned at a low relative humidity (e.g. 10-35%) for 24 hours before exposing to the standard atmosphere conditions. The temperature in this case is not critical but should be around 20℃. (Borch etc 2002)

For quality control purposes in paper and board mills it is usually necessary to test a product immediately it comes from the machine, without adequate conditioning and frequently using a test method which has been modified to give results in the shortest possible time. The moisture content off-machine is usually lower that the equilibrium value after conditioning and this affects the paper properties, especially strength, and therefore off-machine testing only provides a guide to the values, which would be obtained after conditioning. It is however, acceptable to use off machine testing provided that the shortcomings are recognised. Individual mills should ensure that they understand how the results from such tests correlate with those using standard methods and conditioned samples, so that meaningful interpretation of results can be achieved. (Borch etc 2002)

Other influencing factors in the testing environment can be vibration, cleanliness, illumination, magnetism and electromagnetism. The significance of the factors varies from test to test. Their size requires consideration from case to case. (Levlin & Söderhjelm 1999, p.264)

6.6 Personnel

The effect of an operator on the uncertainty of measurement depends highly on the test material, sampling, test method and equipment used. The influence of the operator begins at sampling when he/she chooses the place from which to take the specimen and the place in the specimen to cut the test pieces. A large variation can exist from operator to operator without proper definition of the test method or sufficient instructions on the procedure. Education and experience of operators have important roles in minimizing variation. If a method uses subjective observation and evaluation of phenomena, the competence of the operator is an important factor creating uncertainty. Developments in testing equipment is making testing increasingly more objective. (Levlin & Söderhjelm 1999, p.264)

7 PHYSICAL PROPERTIES OF PAPER AND BOARD

Many different physical properties can describe paper and board. Some properties relate to the end use of the paper or board. Grouping of the properties can be as follows:

- Basic properties
- Strength properties

- Stiffness properties
- Structural properties
- Surface properties
- Absorption properties
- Optical properties

There are a lot of different methods available for the measurement of these properties. The methods used are based on standards that describe details of different tests. Usually tests are performed by ISO standards and also measurements done in this work are based on ISO standards. Other available standards come from SCAN, TAPPI and EN. (Levlin & Söderhjelm 1999, p.137)

Many tests for the general physical properties of paper and board can be carried out on-line on the paper machine for process control purposes. Many automated paper testing procedures are also available to increase the productivity of routine paper testing in production control laboratories. These paper testing systems in most cases apply the same basic testing principles developed for common laboratory testing procedures. (Levlin & Söderhjelm 1999, p.138; Rance, H. F. 1982)

7.1 Basic properties

The basic properties of paper and board include grammage, moisture, thickness, density, bulk and filler content. Paper and board trades on a weight basis which is linked to surface area of the material. The thickness and density are also important properties for describing the nature of the paper structure. (Levlin & Söderhjelm 1999, p.140)

7.1.1 Grammage

Grammage is defined as the weight in grammes per unit area of paper or board expressed as g/m². Grammage, together with thickness, are significant properties in the sale and use of the paper product. Many other physical properties are often expressed as a unit grammage. In the USA the term “basis weight” is used and whilst the term grammage is now widely used and accepted, the previously used term “substance” is still occasionally encountered. (Niskanen 2008, p.14)

Determination of grammage involves weighing a piece of paper with a known area, ISO 536. For this purpose, test pieces with an area of at least 500 cm^2, preferably 200 x 250 mm, are cut with a precision of ± 0.5 mm. For precision work there is available test piece punching equipment. (Levlin & Söderhjelm 1999)

Grammage can be calculated when the mass and area of the sample is known with the following formula:

$$g = \frac{m}{A} x\ 10000 \qquad (1)$$

where m is the mass of the test piece in grams

A is the area of the test piece in square centimeters.

7.1.2 Moisture

The moisture content of pulp, paper and board is important for both economic and end use purposes. For pulp the moisture is required to be known for economic reasons as this product is sold on an “air dry” basis. In paper and board the moisture content effects such properties as dimensional stability, physical strength, paper runnability, calendering, embossing and in particular printability. (Niskanen 2008; Scott W. E. & Trosset S. 1989)

Determination of the paper moisture involves weighing a sample of the paper before and after drying at 105 ± 2 ℃, ISO 287. A s ufficiently long drying time is needed for reaching the required constant sample weight. The moisture content is expressed as a percentage of the weight of the moist sample. This is the only testing method of the moisture that is accepted for standards. (Levlin & Söderhjelm 1999)

7.1.3 Thickness, bulk and density

The measurement of paper thickness is a key characteristic in the assessment of a paper product quality. When thickness measurements are related to grammage, the ratio of these two parameters will give a value for apparent sheet bulk, or its reciprocal, apparent sheet density. Values for bulk are part of some product specifications, e.g. book papers. Sheet density directly influences many other paper properties such as strength and opacity when it is altered during forming and/or pressing. Changes in density during calendering have less effect on other properties. (Levlin & Söderhjelm 1999, p.140; Niskanen 2008, p.20)

The thickness of paper and board may be measured either on a single sheet or a pad of sheets. The decision as to the number of sheets to be tested is related to the purpose of the test. The measurement is performed by pressing the sheet or a pad of sheets between two parallel plates with given pressure. The preferred pressure is 100 kPa, ISO 534. The normal expression for thickness of paper is µm. (Levlin & Söderhjelm 1999; Scott W. E. & Trosset S. 1989)

While the single sheet thickness measurement uses a single sheet, the bulking thickness is the average thickness of a sheet of paper measured from a pad of sheets. The bulking thickness value is usually lower than the single sheet thickness value because of the variations and compressibility of paper and the uneven character of its surface. (Levlin & Söderhjelm 1999)

Which thickness value to use in a specific case depends on the purpose for using the results. The single sheet thickness is often relevant for an end-use situation such as a printing process. Bulking thickness indicates the final thickness of a book produced from the paper concerned. (Levlin & Söderhjelm 1999)

Apparent density is the mass per unit volume of the paper or board calculated as the ratio between basis weight and thickness of the material in kg/m^3. Sometimes the units are g/cm^3. (Levlin & Söderhjelm 1999, p.141)

According to ISO 534, 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 of density:

$$Bulk = \frac{1}{density}\ ,\ expressed\ as\ cm^3/g \qquad (2)$$

Paper manufacturers and customers often prefer to use bulk as a characteristic for density of paper because the required end-use properties of paper would often be combined with a paper density as low as possible. (Levlin & Söderhjelm, p.141)

7.2 Strength properties

The most important strength properties of paper or board include:

- Tensile strength
- Bursting strength
- Tearing strength
- Bending stiffness
- Bonding strength

Strength properties of paper are in great importance in process controlling and with the end product requirements. (Levlin & Söderhjelm 1999)

7.2.1 Tensile strength

Tensile strength describes well the general strength of any material. For paper tensile strength is the maximum force per unit width that a paper strip can resist before breaking when applying the load in a direction parallel to the length of the strip. Measurement uses testers applying either a constant rate of loading, ISO 1924-1, or a constant rate of elongation for loading the strip, ISO 1924-2. (Levlin & Söderhjelm 1999, p.142; Scott W. E. & Trosset S. 1989)

In the tensile strength tester, the test piece is stretched to the point where rupture occurs. The maximum tensile force the test piece can withstand before it breaks and the corresponding elongation of the strip are measured and recorded. Tensile strength expression uses kN/m. (Levlin & Söderhjelm 1999, p.142; Scott W. E. & Trosset S. 1989)

From the tensile strength measured, calculation of the tensile index uses the following formula.

$$Tensile\ index = tensile\ strength/grammage \qquad (3)$$

The units for tensile strength index are Nm/g.

The tensile strength index value relates strength to the amount of material being loaded. Tensile index therefore has primary use to describe the strength of pulps. Characterization of papers usually uses the tensile strength value as such. The reason is that paper is an end product for which tensile strength is an important characteristic. (Levlin & Söderhjelm 1999, p.142)

The elongation or stretch at break is the increase in length of the strip to its breaking point expressed in percentage of the original length. For most paper grades, stretch is 1 – 5%, but values higher than 20% can be found for certain grades such as tissue papers. (Levlin & Söderhjelm 1999, p.142)

A tensile tester measures the load applied as a function of elongation of the sample trip. If the tester has a recorder as is the case with modern testing equipment, the load-elongation (stress-strain) curve results automatically. Besides the maximum load that gives the tensile strength of the strip and the elongation, such a curve also gives the tensile energy absorption. This quantity is the work required to break the strip. Mathematically, the tensile energy absorption, W, has the following definition. (Levlin & Söderhjelm 1999, p.142)

$$W = \int F\, dl \qquad (4)$$

where F is the force and dl is the corresponding elongation.

Tensile strength of a paper depends on fiber strength but primarily on the degree of bonding between fibers. It therefore has frequent use in pulp testing as a general characteristic for the capability of bonding between fibers. The result obtained also depends on the testing conditions. An increase in the rate of loading will increase the tensile strength. An increase in moisture content of the paper will decrease the tensile strength while increasing elongation. (Levlin & Söderhjelm 1999, p.143)

The tensile strength is highly dependant on directionality of the paper. The tensile strength measured in different directions of the sheet is often used as an indicator of fiber orientation. (Levlin & Söderhjelm 1999, p.144)

Tensile test sometime uses test pieces saturated with a liquid such as water, ISO 3781. This wet strength value indicates the retention of strength value indicates the retention of strength of the paper after wetting. (Levlin & Söderhjelm 1999, p.144)

Wet strength value differs from the initial wet web strength value that gives the tensile strength of the web before its first drying cycle. This measurement is a tensile value of laboratory sheets at a certain solids content or at the solids content obtained with a standardized dewatering procedure. It is a pulp or furnish property that relates to the runnability of a paper machine, SCAN-C 31 and C 35. (Levlin & Söderhjelm 1999, p.144; Scott W. E. & Trosset S. 1989)

7.2.2 Bursting strength

Bursting strength is one of the oldest tests developed for paper and board and it is a general indicator of strength characteristics. This test is extensively used in the testing programmes for packaging papers and also in the evaluation of wood pulps. The most attractive feature of this test is that it is very quick and easy to carry out and can be done directly on samples from the paper machine web, without any specific test specimen preparation. (Levlin & Söderhjelm 1999; Rance, H. F. 1982)

The burst strength is influenced by many factors in papermaking, such as the fibre type, degree of refining, presence of strength additives (e.g. Starch), sheet formation, and moisture content. On refining, burst strength increases as the fibre bonding increases, provided there is not too much fibre shortening. (Levlin & Söderhjelm 1999; Rance, H. F. 1982)

Bursting strength is the maximum pressure that the paper can resist without breaking with pressure applied perpendicular to the plane of the test piece. The unit for bursting strength is kilopascal, kPa. Calculation of the material related burst index uses the following formula:

$$Burst\ index = bursting\ strength/basis\ weight \qquad (5)$$

Burst index expression uses kPa x m²/g.

The bursting test for paper is described in ISO 2758 and for board in ISO 2759. Bursting strength is an old test for paper strength. It is a rapid and easy test to perform and does not require test pieces cut exactly. Furthermore, it can not be measured as a function of the directionality of the paper. The burst test has been developed empirically. It is not clearly defined in physical terms. Bursting strength somehow relates mathematically and physically to the tensile strength and elongation of paper. (Levlin & Söderhjelm 1999, p.144)

Bursting energy absorption is another related measurement. This is the bursting work done per unit are of the paper or board when stretched to rupture. (Levlin & Söderhjelm 1999, p.144)

The most common tester used for bursting strength measurements is the Mullen tester. A test piece placed over a circular elastic diaphragm is rigidly clamped at the periphery but free to bulge with diaphragm. The hydraulic fluid pressure increases by pumping at a constant rate to bulge the diaphragm until the test piece ruptures. The bursting strength of the test piece is the maximum value of the applied hydraulic pressure. The tester itself and especially the pressure measuring manometers are sensitive to errors that often make the results unreliable. In modern testers, these manometers have been replaced by electronic pressure transducers that are much more reliable. (Levlin & Söderhjelm 1999, p.144)

7.2.3 Tearing resistance

The tearing strength of paper and board is generally dependent on fibre length over most of its refining range. The fibre strength, bonding degree between fibres and the fibre orientation in the sheet, also influences the tear strength. It is a particularly useful test for paper used as a wrapper to protect materials in transit or any paper subject to tearing strains in use. (Levlin & Söderhjelm 1999; Rance, H. F. 1982)

Tearing strength or internal tearing resistance is the mean force required to continue the tearing of paper from an initial cut in a single sheet, ISO 1974, or a pad of sheets. If this cut is in the machine direction, the result is machine direction tearing resistance. Correspondingly, the cross direction tearing resistance is the result of a test in the cross direction. The tearing strength is highly dependent on the fiber orientation of the sheet. The unit for tearing strength is newton (N) or millinewton (mN). (Levlin & Söderhjelm 1999, p.145)
From tearing strength, calculation of the tear index uses the following formula:

$$Tear\ index = tearing\ strength / basis\ weight \tag{6}$$

Tear index units are mN x m²/g.

The tear testers measure the work required to produce a certain tear. If the tear remains constant, the value obtained is directly proportional to the tearing strength. The most common test method is the “Elmendorf Tear Test”. This method uses a pendulum instrument to measure the force required to continue tearing an initial slit in a sheet or sheets of paper or board. Normally an initial slit is pre-cut in four sheets simultaneously, but in some cases a smaller number may be used. (Borch etc 2002)

7.2.4 Bending resistance

Stiffness is a measure of a paper’s ability to support its own weight. The stiffness of paper varies significantly with the type produced and is dependent on the fibers used, fiber treatment (refining), the paper grammage and its bulk. The paper stiffness in office/business papers and printing papers is important for its performance on these imaging machines. This property is also important in the performance of paper and board in packaging machines. (Niskanen 2008; Rance, H. F. 1982)

Bending stiffness describes the ability of a paper or board strip to resist a bending force applied perpendicular to the free end of a strip clamped at the free end of a strip clamped at the other end, 2-point loading method. The force required to bend the strip to a specified angle is the bending resistance. In practice, the strip and dimensions and the bending angle remain constant. The bending stiffness therefore relates directly to the bending resistance measured as the bending moment (force x bending length). (Levlin & Söderhjelm 1999)

The bending stiffness relates to modulus of elasticity and thickness of a uniform beam of any material via the following formula:

$$S = \frac{El}{b} = \frac{Eh^3}{12} \qquad (7)$$

where S = stiffness

E = modulus of elasticity

I = the moment of inertia of the sample

h = thickness of the sample

b = the width of the sample.

There are several methods available for measuring the bending stiffness of paper and board. They employ a static principle where the force needed to cause certain deflection is measured or a dynamic principle also known as the resonance method. (Levlin & Söderhjelm 1999)

The general principles of different static methods are described in ISO 5628. They include the 2-point, 3-point and 4-point methods for loading the sample. The most common technique for practical paper and board testing is the 2-point method. The 3-point method has little use. The 4-point method is used only with thick boards and converted products such as corrugated fiberboard. (Levlin & Söderhjelm 1999)

In the 2-point method (Fig. 1), the test piece is clamped at one end. The other end is forced to deflect a certain amount. The force needed to cause the deflection is determined and used as a measure of the bending stiffness of the material. (Levlin & Söderhjelm 1999)

The measured property is usually called bending resistance to emphasize the point that it does not necessarily reflect the true bending stiffness of the material. This is because the loading mode in a 2-point bending test does not comply with theoretically ideal conditions of pure bending. (Levlin & Söderhjelm 1999, p.152)

Many standards define the bending resistance according to the 2-point method, including SCAN-P 29, TAPPI T 556. The width of the test piece is 38 mm. For boards, the free length is 50 mm and the deflection is 15° or 7,5°. For papers, the free length must often be reduced to 10 mm to keep the force at a measurable level. (Levlin & Söderhjelm 1999, p.153)

The result is usually expressed as the force in millinewtons (mN) needed to cause the specified deflection to the test piece. It is sometimes expressed as the bending moment, i.e., the bending resistance multiplied by the free length of the bent sample. In either case, the test result also includes the dimensions of the test piece and the degree of deflection as parameters. (Levlin & Söderhjelm 1999, p.153)

Although the loading mode in the 2-point method is not ideal from a physical consideration, the arrangement can satisfactorily estimate the bending stiffness provided the test piece is long in relation to the thickness of the material and the deflection is sufficiently small. The subsequent strains in the test piece should remain within the elastic region, i.e. $\Delta l / l_0$ below 0,2%. (Levlin & Söderhjelm 1999, p.153)

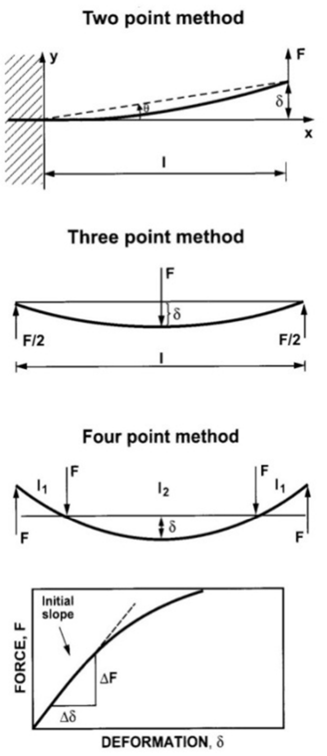

Figure 1. The 2-, 3- and 4-point methods for measuring bending stiffness. (Levlin & Söderhjelm 1999)

In the figure 1 can be seen the difference measuring bending stiffness with 2-, 3- and 4-point methods and the force relation to deformation. In the 3- and 4-point loading, the part of the test piece that lies between the supports of the test piece undergoes pure bending. Care is also necessary here to keep the deflection and the resulting strains in the test piece within the elastic region of the material. (Levlin & Söderhjelm 1999)

In practice, the curvature is estimated from the mid-point deflection of the test piece and the distance between the supports. The bending moment between the supports is uniform and determined by the loads at the ends of the test piece and the length of the free ends. (Levlin & Söderhjelm 1999, p.154)

The bending stiffness of a layered structure such as a multi-ply board depends on the sum of the stiffness properties of the individual plies and of their position in relation to the neutral plane of the multi-ply board when bended:

$$S = \sum(Ei\ x\ Ii)/b \quad (8)$$

where S = bending stiffness

E_i= modulus of elasticity

I_i = moment of inertia of the ply i in the structure

b = width of the test piece.

(Levlin & Söderhjelm 1999)

7.2.5 Bonding strength

In a paper sheet, the deformation of any inter-fiber bond involves corresponding deformations in the fiber segments that bond the couples. The mechanical response of the bond cannot be separated from the response of the bonded fiber segments. Even the bonding layer between two fibers is sometimes difficult to identify and separate from the actual fiber wall. The mechanical properties of paper can be entirely described by the properties of the bonded and free fiber segments. In this approximation, the only role of the bonds is to define where the surface elements of a fiber couple to the surface elements of another fiber. (Niskanen 2008; Rance, H. F. 1982)

Bonding strength, or as it is often also called z-directional strength, is defined as the average work required to split the test piece of known size (1 square inch) in the plane of the sheet into two plies (Internal Bond) or to separate the layers of a multi-ply board (Ply Bond). Because a break in the paper occurs in the sheet but not at its surface, the bonding strength is not equivalent to the surface strength or linting tendency of the paper. (Aaltonen 1994, Levlin & Söderhjelm 1999)

Many descriptions of ways to measure bonding strength of paper are available. Standardized methods are TAPPI UM 584, TAPPI UM 403, TAPPI UM 527 and TAPPI UM 528. (Levlin & Söderhjelm 1999)

In a direct measurement of the bonding strength, the paper sample is mounted with double sided tape or glue between two metal pieces which are forced together under load to ensure that the plates are well attached to the paper. This assembly is mounted in a tensile tester and loaded until the sheet splits. The bonding strength is the load at break divided by the area of the sheet. (Levlin & Söderhjelm 1999)

The most common apparatus for measuring bonding strength is the Scott bond tester, TAPPI UM 403. In this case, the sample is mounted between a metal plate and an angle of aluminum as is shown in Fig. 2.

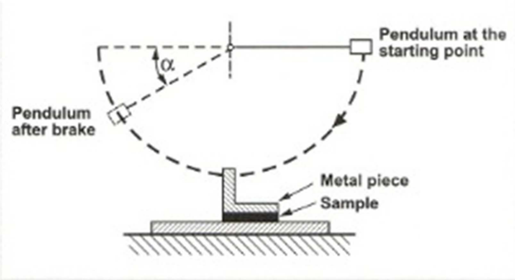

Figure 2. Principle of the Scott bond tester. (Levlin 1999)

In the figure 2 is described the principle of the Scott bond tester. A double-sided tape mounts the sample on the metal pieces. A pendulum then hits the aluminum angle piece and loads the paper sample until it breaks. The loss of kinetic energy of the pendulum after it hits the aluminum angle indicates the strength of the paper. (Levlin & Söderhjelm 1999, p.165)

8 THE REFERENCE MEASUREMENTS

There are a lot of different tests and testing methods for measuring the properties of the paper and board. The measured properties in this work were limited to the most common basic and strength properties of paper and board. With the own samples, only grammages and strength properties were measured. From the measurements were calculated the average, standard deviation, standard error of mean and confidence interval with 95% probability which gives the range for each measured property. Confidence limits can be calculated with the following formula:

$$Y \pm = t_{(\alpha/2,N-1)} s/\sqrt{N} \qquad (9)$$

where Y is the sample mean, s is the sample standard deviation, N is the sample size, α is the desired significance level, and $t_{(\alpha/2,N-1)}$ is the upper critical value of the t distribution with N - 1 degrees of freedom. The confidence coefficient is 1 - α. The upper and lower confidence limits are expressed in results as y min and y max. (http://www.itl.nist.gov/div898/handbook/eda/section3/eda352.htm)

The standard error of the mean (SEM) is the standard deviation of the sample-mean estimate of a population mean. It can also be viewed as the standard deviation of the error in the sample mean relative to the true mean, since the sample mean is an unbiased estimator. SEM is usually estimated by the sample estimate of the population divided by the square root of the sample size:

$$SE_x = \frac{s}{\sqrt{n}} \qquad (10)$$

where s is the sample standard deviation (i.e., the sample-based estimate of the standard deviation of the population), and n is the size (number of observations) of the sample. (http://www.experiment-resources.com/standard-error-of-the-mean.html)

8.1 Samples

The samples of the industrial manufactured papers and boards are from Stora Enso Imatra mills and M-real Simpele mill. Own sheets were made of birch, eucalyptus, pine and spruce pulps which are manufactured in Stora Enso Kaukopää mill, Imatra. The target grammage for own sheets was 80 g/m². The following paper and board samples are from the paper mills:

- Simcastor plus 45 g/m², printing paper, M-real, Simpele
- Lumiflex 80 g/m², printing paper, Stora Enso Kaukopää, Imatra
- Cupforma 170 g/m², cupstock, Stora Enso Tainionkoski, Imatra
- Simcote 250 g/m², folding boxboard, M-real, Simpele

- Ensogloss 240 g/m², printing board, Stora Enso Kaukopää, Imatra

The paper and board samples used can be found from the paper laboratory of the school and are commonly used in the student works. Own sheets were made of the factory-made pulpsheets that are also available in the paper laboratory. Samples were conditioned by storing them in laboratory at standardized atmosphere (23 ± 1 ℃; 50 ± 2 %). Tests were performed by the instructions of ISO standards.

8.2 Basic properties

Measured basic properties of paper and board samples in this work were grammage, moisture and thickness.

8.2.1 Grammage

Determination of grammage was performed by the ISO 536:1995 (E) (appendix 8). Samples from the paper mills were cut to size 200 x 250 mm, which gives the test samples area of 500 cm². With the own samples the mass was measured from the whole sheet and calculated from the sheet´s area of 310 cm². Grammage can be calculated with the formula 1 when the mass and area of the test piece is known. The number of measurements was 10 with the samples from paper mills and with the own sheets each one was measured. (Detailed test results are listed in appendix 1).

Table 1. Grammages of the paper mill samples.

	Simcastor	Lumiflex	Simcote	Cupforma	Ensogloss
Average	46,2	79,6	251,1	168,1	238,3
St. Dev	0,65	0,23	0,68	0,72	0,65
y min	45,4	79,4	250,2	167,2	237,5
y max	47,0	79,9	251,9	169,0	239,1
SEM	0,21	0,07	0,22	0,23	0,21

As it is seen from the table 1, the measured average grammages from the paper mill samples differ less than 2 g from the published value. Measured values are in a tight range with less than 1 g standard deviation.

Table 2. Grammages of the own sheets.

	Birch	Eucalyptus	Pine	Spruce
Average (g/m²)	79,5	83,3	82,9	81,6
St. dev (g/m²)	1,71	2,79	3,55	1,31
y min	78,7	82,0	81,2	81,0
y max	80,3	84,6	84,6	82,3
SEM	0,38	0,62	0,79	0,29

In the table 2 is shown the grammages of the own sheets. There was lot more deviation than in the samples of paper mills, especially the standard deviation of eucalyptus and pine sheets differs notably from the aimed 80 g/m². There occurs fiber losses during sheet preparation which causes deviation in grammage. (Detailed test results are listed in appendix 1).

8.2.2 Moisture

The moisture of the paper and board samples was tested with the oven-drying method as well as using infrared scale -instrument. The ISO 287-1985 (E) (appendix 8) determines the oven-drying method. With the oven-drying method, the sample is dried in the oven which maintains the air temperature at 105 ± 2 ℃. The drying time was at least 1 day with every sample. The mass of the sample is measured before and after drying and the moisture content can be calculated from the mass difference. The moisture content is expressed in percents. The infrared scale –instrument is quick way to measure the moisture but this method is not under any recognized standard. The reference measurements of the moisture were measured only from the paper mill samples.

Table 3. Moisture of the paper mill samples, oven-drying method.

	Average (%)	St. dev. (%)	y min	y max	SEM
Simcastor plus 45 g/m²	10,8	1,3	9,9	11,7	0,41
Lumiflex 90 g/m²	9	0,7	8,5	9,5	0,22
Simcote 240 g/m²	9,4	0,9	8,8	10,0	0,28
Cupforma 170 g/m²	8,8	0,8	8,2	9,4	0,25
Ensogloss 250 g/m²	7,5	0,7	7,0	8,0	0,22

In the table 3 is the test results of the moisture measured with oven-drying method. Simcastor plus –sample had more moisture compared to other paper and board samples. There was also much more deviation with Simcastor plus compared to other samples. The average moisture went within ± 1 %, except Simcastor plus which had the measured moisture range of 10,8 ± 1,3 %. (Detailed test results are listed in appendix 2).

Table 4. Moisture of the paper mill samples, infrared scale –method.

	Average (%)	St. dev. (%)	y min	y max	SEM
Simcastor plus 45 g/m²	11,2	1,7	10,4	12,0	0,54
Lumiflex 90 g/m²	7	1	6,6	7,4	0,32
Simcote 240 g/m²	7,6	1	7,1	8,1	0,32
Cupforma 170 g/m²	7,2	0,5	6,7	7,7	0,16
Ensogloss 250 g/m²	5,7	0,7	5,3	6,1	0,22

In the table 4 is shown the results of moisture using infrared scale –method. Simcastor plus –sample had even bigger average moisture and standard deviation compared to oven-drying method while with the other samples moistures were less. The deviations with this method were also little bit larger except the deviations of Cupforma and Ensogloss samples. Again only Simcastor plus had the standard deviation bigger than 1 %. (Detailed test results are listed in appendix 2).

8.2.3 Thickness

Thickness of the paper and board was measured with (L&W-instrument). With the paper samples, the thickness was determined by measuring the 8 sheets ply and dividing the result by the number of the sheets. Thickness of boards was measured from a single sheet. The thickness was measured from the paper mill samples. The ISO standard for thickness is ISO 534:1988(E) (appendix 8).

Table 5. Thickness of the paper mill samples.

	Average (µm)	St. dev. (µm)	y min	y max	SEM
Simcastor plus 45 g/m²	39,2	0,3	39,0	39,5	0,10
Lumiflex 80 g/m²	81,6	0,2	81,4	81,8	0,08
Simcote 250 g/m²	444,4	2,1	442,9	445,9	0,67
Ensogloss 240 g/m²	300,1	3,0	297,9	302,3	0,96
Cupforma 170 g/m²	211,1	1,7	209,9	212,3	0,53

From the table 5 can be seen the averages and standard deviations of the paper mill samples. With the paper grades (Simcastor plus and Lumiflex) the standard deviation was less than with the board grades. (Detailed test results are listed in appendix 3).

8.3 Strength properties

The strength properties performed in this work were tensile strength, bursting strength, tearing resistance, bending resistance and bonding strength. Strength properties were measured from the paper mill samples and own sheets.

8.3.1 Tensile strength

Tensile strength was measured with the “Testometric Micro 350” –instrument. The value of tensile speed was set to 100 mm/min and the used range was 1000 N/T. The size of test piece was 15 mm width and 180 mm length. The tensile index was calculated by dividing the tensile strength with the grammage of the sample (formula 2). With each sample was performed the machine- and cross direction tensile strength.The machine direction tensile strength is notably higher because of the formation of the fibres and the fibre bonds have more strength in machine direction. The standard used is ISO 1924 - 1:1992(E) (appendix 8).

Table 6. Tensile strength of Simcastor plus.

	MD	CD
Tensile strength average (N)	3,48	1,37
Tensile strength st. dev.(N)	0,27	0,05
Elongation average (mm)	2,0	5,8
Elongation st. dev. (mm)	0,2	0,6
Tensile index average (Nm/g)	77,2	30,4
Tensile index st. dev. (Nm/g)	6,0	1,2
y min, tensile index (Nm/g)	72,9	29,5
y max, tensile index (Nm/g)	81,5	31,2
SEM, tensile index (Nm/g)	1,90	0,38

In the table 6 is shown the tensile strength measurements for Simcastor plus in machine direction (MD) and cross direction (CD). The tensile strength and tensile index in machine direction is about 2.5 times higher than in cross direction while the elongation in machine direction is 3 times less. In the machine direction there was also much more deviation in tensile strength and tensile index. The results in the table 6 consist of total 25 repetitions made with Simcastor plus in machine- and cross directions. The first test series was 10 repetitions and the second series 15 repetitions. The reason was to compare how much difference there is in results and does 5 more repetitions give notably less deviation. (Detailed test results are listed in appendix 4).

Table 7. Tensile strength of Simcastor plus in machine direction.

	MD 10 rep	MD 15 rep
Tensile strength average (N)	3,51	3,45
Tensile strength st. dev.(N)	0,15	0,33
Elongation average (mm)	2,02	1,97
Elongation st. dev. (mm)	0,18	0,27
Tensile index average (Nm/g)	78,0	76,7
Tensile index st. dev. (Nm/g)	3,30	7,36

In the table 7 is the comparison between 10 and 15 repetitions in machine direction. Averages got near each others as expected but there was more standard deviation with 15 repetitions.

Table 8. Tensile strength of Simcastor plus in cross direction.

	CD 10 rep	CD 15 rep
Tensile strength average (N)	1,34	1,39
Tensile strength st. dev.(N)	0,06	0,04
Elongation average (mm)	5,77	5,78
Elongation st. dev. (mm)	0,81	0,49
Tensile index average (Nm/g)	29,8	30,8
Tensile index st. dev. (Nm/g)	1,39	0,85

From the table 8 above is seen the difference between 15 and to 10 repetitions in cross direction tensile strength of Simcastor plus. Averages were again very near each others but this time there was less standard deviation with 15 repetitions. (Detailed test results are listed in appendix 4).

Another paper sample from the paper mill, Lumiflex, is much stronger paper than light and thin Simcastor plus. The results for the tensile strength of Lumiflex are listed in the table 9. Measurements were repeated 10 times in both directions. (Detailed test results are listed in appendix 4).

Table 9. Tensile strength of Lumiflex.

	MD	CD
Tensile strength average (N)	6,28	2,44
Tensile strength st. dev.(N)	0,43	0,13
Elongation average (mm)	2,44	5,06
Elongation st. dev. (mm)	0,23	0,57
Tensile index average (Nm/g)	78,5	30,5
Tensile index st. dev. (Nm/g)	5,42	1,65
y min, tensile index (Nm/g)	74,6	29,3
y max, tensile index (Nm/g)	82,4	31,7
SEM, tensile index (Nm/g)	1,71	0,52

As it is seen from the table 9, the machine direction tensile strength and tensile index were again 2.5 times higher than the tensile strength in cross direction. Standard deviation also occurred much more in machine direction tensile strength. Elongation in machine direction is a bit over 2 times less than in cross direction.

First board sample for tensile strength was Simcote 250 g/m². The standard deviation of the tensile strength and tensile index was much less than with the paper samples. Also the difference between machine- and cross direction tensile strength and tensile index was less than with the paper samples, now averaging the MD tensile strength 1.5 times more than CD tensile strength. The standard deviation with the Simcote was very near each other in both directions. There was about 1.5 times more elongation in cross direction. Results are put together in table 10. Measurements were done 10 times in both directions. (Detailed test results are listed in appendix 4).

Table 10. Tensile strength of Simcote.

	MD	CD

Tensile strength average (N)	1,24	0,80
Tensile strength st. dev.(N)	0,02	0,03
Elongation average (mm)	2,64	3,89
Elongation st. dev. (mm)	0,24	0,32
Tensile index average (Nm/g)	4,95	3,20
Tensile index st. dev. (Nm/g)	0,09	0,10
y min, tensile index (Nm/g)	4,89	3,13
y max, tensile index (Nm/g)	5,02	3,27
SEM, tensile index (Nm/g)	0,03	0,03

The tensile strength of biopolymer coated Cupforma 170 g/m² was tested performing 10 measurements in machine- and cross direction. The results are shown in the table 11. (Detailed test results are listed in appendix 4).

Table 11. Tensile strength of Cupforma.

	MD	CD
Tensile strength average (N)	1,88	0,88
Tensile strength st. dev.(N)	0,02	0,02
Elongation average (mm)	2,64	6,86
Elongation st. dev. (mm)	0,13	0,20
Tensile index average (Nm/g)	11,07	5,15
Tensile index st. dev. (Nm/g)	0,14	0,09
y min, tensile index (Nm/g)	10,97	5,09
y max, tensile index (Nm/g)	11,18	5,22
SEM, tensile index (Nm/g)	0,05	0,03

The machine direction tensile strength and tensile index of Cupforma was a bit over 2 times more than in cross direction as it can be seen from the table 11 above. There was very little standard deviation in tensile strength. Elongation in cross direction was about 2.6 times more compared to machine direction.

The tensile strength of the Ensogloss 240 g/m² is expressed in the table 12. With this board sample, the cross direction tensile strength and tensile index were about 1.5 times bigger than in machine direction. Elongation was well over 2 times more in cross direction compared to machine direction. (Detailed test results are listed in appendix 4).

Table 12. Tensile strength of Ensogloss.

	MD	CD
Tensile strength average (N/mm)	1,90	1,22
Tensile strength st. dev.(N/mm)	0,06	0,03
Elongation average (mm)	3,09	6,90
Elongation st. dev. (mm)	0,09	0,33
Tensile index average (Nm/g)	7,91	5,09
Tensile index st. dev. (Nm/g)	0,23	0,14
y min, tensile index (Nm/g)	7,74	4,99
y max, tensile index (Nm/g)	8,07	5,19
SEM, tensile index (Nm/g)	0,07	0,04

With the own sheets fibres are formated randomly and there is not such directions as papers made in paper machines. In the table 13 are the results of the tensile strength of the own sheets. (Detailed test results are listed in appendix 4).

Table 13. Tensile strength of the own sheets.

	Eucalyptus	Birch	Pine	Spruce
Tensile strength average (N/mm)	2,09	2,29	3,57	2,23
Tensile strength st. dev.(N/mm)	0,09	0,16	0,27	0,16
Elongation average (mm)	1,39	1,38	2,78	1,50
Elongation st. dev. (mm)	0,10	0,14	0,41	0,16
Tensile index average (Nm/g)	39,23	42,89	66,97	41,74
Tensile index st. dev. (Nm/g)	1,72	2,98	5,00	3,01
y min, tensile index (Nm/g)	37,99	40,75	63,39	39,59
y max, tensile index (Nm/g)	40,46	45,02	70,55	43,89
SEM, tensile index (Nm/g)	0,55	0,94	1,58	0,95

As it is seen from the table 13, pine had notably bigger tensile strength and tensile index than with the other own samples. The tensile strengths of birch and spruce were very near each other. Eucalyptus had the smallest tensile strength but it was still near birch and spruce. Pine had also almost two times more elongation than other samples. The elongation of eucalyptus, birch and spruce was about the same. There was most deviation with the tensile strength of pine and least with eucalyptus.

8.3.2 Bursting strength

Bursting strength was measured with the “Lorentzen & Wettre - Burst-o-matic” - instrument. Measurements were taken from the smooth side of paper and the amount of measurements with each sample was 10. Used pressure was 1606 kPa. The used standard for the burst strength is ISO 2758:1983(E). The results of the paper mill samples are shown in the table 14 below. (Detailed test results are listed in appendix 5).

Table 14. Bursting strength of the paper mill samples.

	Simcastor plus 45 g/m²	Lumiflex 80 g/m²	Simcote 250 g/m²	Ensogloss 240 g/m²	Cupforma 170 g/m²
Average (KPa)	139,20	249,50	416,20	961,40	778,70
St. dev. (KPa)	6,89	7,58	24,56	31,91	28,79
y min (kPa)	134,27	244,08	398,63	938,57	758,11
y max (kPa)	144,13	254,92	433,77	984,23	799,29
SEM (kPa)	2,18	2,40	7,77	10,09	9,10
Burst index (kPa x m²/g)	3,09	3,12	1,66	4,01	4,58

It can be seen from the table 14 that the standard deviation of the bursting strength with Simcastor plus and Lumiflex was lot less than with the board samples. It seems like the more the bursting strength, the more there is also deviation and standard error of mean. Biopolymer coated Cupforma and double coated Ensogloss had significant bursting strength.

In the chart 15 is shown the burst indexes of the paper mill samples. Both paper samples, Simcastor plus and Lumiflex, had almost equal burst index. Cupforma had the highest burst index because it has polymer coated multilayer which gives good bursting strength. Simcote had lowest burst index.

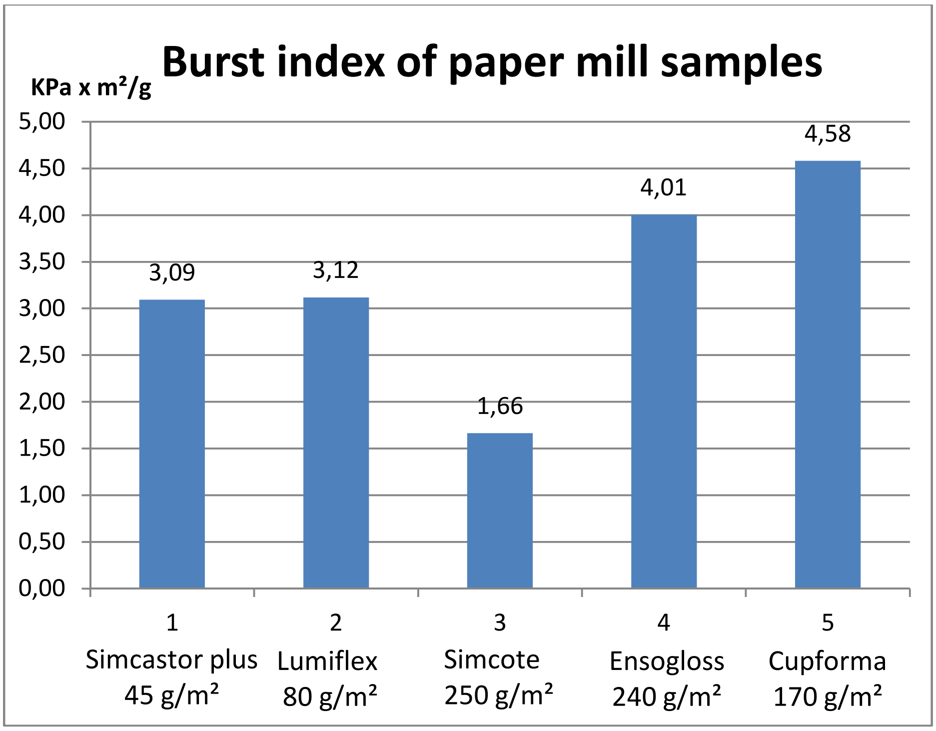

Chart 15. Burst index of the paper mill samples.

The bursting strength of the own sheets is shown in the table 16. Pine had almost 3 times higher burst strength compared to other samples. Eucalyptus and birch were near each other and the bursting strength of spruce is little bit higher compared to eucalyptus and birch. With this test, pine had also lot more deviation than other samples. (Detailed test results are listed in appendix 5).

Table 16. Bursting strength of the own sheets.

	Eucalyptus	Birch	Pine	Spruce
Average (kPa)	115,20	109,80	321,20	130,30
St. dev. (kPa)	3,26	3,99	11,26	4,06
y min (kPa)	112,87	106,94	313,14	127,40
y max (kPa)	117,53	112,66	329,26	133,20
SEM (kPa)	1,03	1,26	3,56	1,28
Burst index (kPa x m²/g)	1,44	1,37	4,02	1,63

In the chart 17 is shown the burst indexes of the own sheets. Pine had superior burst index compared to other samples. Eucalyptus and birch had only little difference in burst index. Spruce had little bit higher burst index compared to eucalyptus and birch.

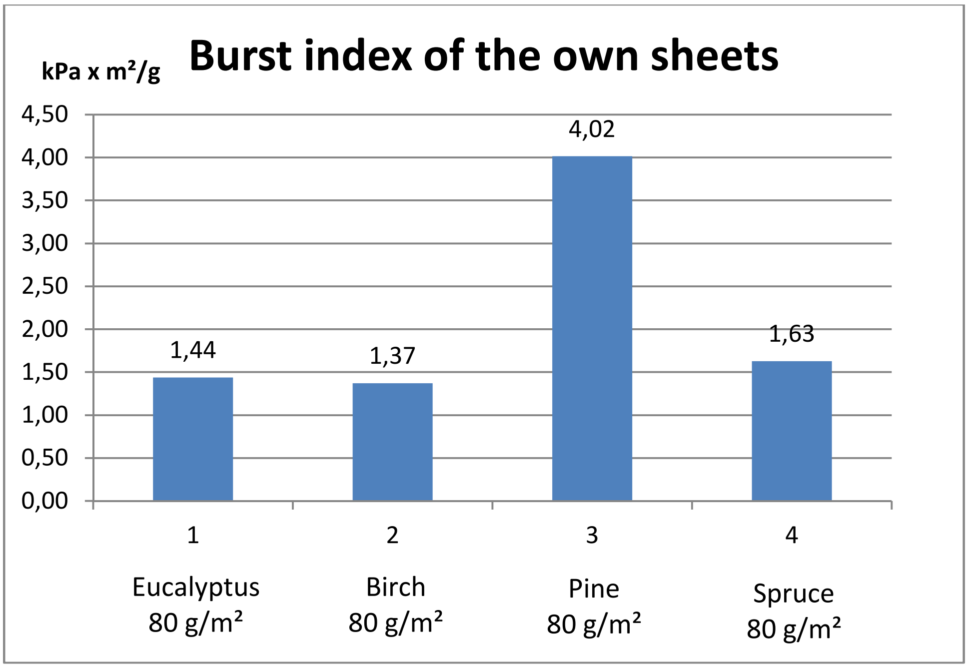

Chart 17. Burst index of the own sheets.

8.3.3 Tearing resistance

Tearing resistance was measured with the Messmer Büchel Digi-Tear instrument. Test method is called the “Elmendorf Tear Test” and the used standard for this test was ISO 1974:1990. The size of test piece was 50 x 63 mm and test was repeated 10 times with each sample. Test was done with the samples in machine- and cross direction. The measurements were taken with paper samples in 4 and 6 sheets plies and boards were measured from a single sheet. Simcastor plus was measured with 10 sheets ply because this paper was too weak to get results with less sheets in ply. In the table 16 is shown the results of the Simcastor plus measured with 10 sheets ply. (Detailed test results are listed in appendix 6).

Table 16. Tearing resistance of Simcastor plus 45 g/m², 10 sheets ply.

	MD	CD
Tearing resistance average (mN)	143,40	181,50
Tearing resistance st. dev.(mN)	5,36	7,12
Tear index average (mN·m²/g)	3,19	4,03
Tear index st. dev. (mN·m²/g)	0,12	0,16
y min, tear index (mN·m²/g)	3,12	3,94
y max, tear index (mN·m²/g)	3,26	4,13
SEM, tear index (mN·m²/g)	0,04	0,05

Tearing resistance of the Lumiflex 80 g/m² in cross direction was about 130 mN higher and there was almost 4 times more deviation compared to machine direction (Table 17). (Detailed test results are listed in appendix 6).

Table 17. Tearing resistance of Lumiflex 80 g/m², 4 sheets ply.

	MD	CD
Tearing resistance average (mN)	464,40	593,60
Tearing resistance st. dev.(mN)	5,50	20,58
Tear index average (mN·m²/g)	5,81	7,42
Tear index st. dev. (mN·m²/g)	0,07	0,26
y min, tear index (mN·m²/g)	5,77	7,27
y max, tear index (mN·m²/g)	5,84	7,57
SEM, tear index (mN·m²/g)	0,02	0,08

In the table 18 is shown the tearing resistance of Cupforma 170 g/m² measured from the single sheet. Tearing resistance and tearing index were almost the same which is quite special. This is explained by the biopolymer coating which gives the better and more stable strength properties. (Detailed test results are listed in appendix 6).

Table 18. Tearing resistance of Cupforma 170 g/m², single sheet.

	MD	CD
Tearing resistance average (mN)	1495,80	1500,60
Tearing resistance st. dev.(mN)	39,32	45,49
Tear index average (mN·m²/g)	8,80	8,83
Tear index st. dev. (mN·m²/g)	0,23	0,27
y min, tear index (mN·m²/g)	8,66	8,67
y max, tear index (mN·m²/g)	8,93	8,98
SEM, tear index (mN·m²/g)	0,07	0,08

Tearing resistance of Ensogloss 240 g/m² is shown in the table 19. Tearing resistance is clearly higher in cross direction and there was also more deviation in results. (Detailed test results are listed in appendix 6).

Table 19. Tearing resistance of Ensogloss 240 g/m², single sheet.

	MD	CD
Tearing resistance average (mN)	1895,20	2063,10
Tearing resistance st. dev.(mN)	49,91	133,04
Tear index average (mN·m²/g)	7,90	8,60
Tear index st. dev. (mN·m²/g)	0,21	0,55
y min, tear index (mN·m²/g)	7,78	8,27
y max, tear index (mN·m²/g)	8,02	8,92
SEM, tear index (mN·m²/g)	0,07	0,18

Tearing resistance of Simcote 250 g/m² is seen from the table 20. There was clear difference between machine -and cross direction tearing strength. Cross direction tearing resistance was about 700 mN bigger compared to machine direction while tear index was 1,5 times more. (Detailed test results are listed in appendix 6).

Table 20. Tearing resistance of Simcote 250 g/m², single sheet.

	MD	CD
Tearing resistance average (mN)	1430,80	2130,40
Tearing resistance st. dev.(mN)	45,06	141,39
Tear index average (mN·m²/g)	5,72	8,52
Tear index st. dev. (mN·m²/g)	0,18	0,57
y min, tear index (mN·m²/g)	5,62	8,19
y max, tear index (mN·m²/g)	5,83	8,85
SEM, tear index (mN·m²/g)	0,06	0,18

8.3.4 Bending resistance

Bending resistance was measured with Messmer Büchel Bending resistance tester –device. The test samples were cut into 38mm x 80mm sized pieces. Bending resistance was measured in machine- and cross direction. For the paper samples used parameters for the test were 15° / 5 mm and for the boards

15° / 50 mm. The determination of bending resistance is described by ISO 2493:1992 (appendix 8). Bending resistance is higher in machine direction.

Table 21. Bending resistance of Simcastor plus 45 g/m².

	MD	CD
Bending resistance average (mN)	28,50	14,20
Bending resistance st. dev.(mN)	2,51	2,44
y min, bending resistance (mN)	27,05	12,79
y max, bending resistance (mN)	29,95	15,61
SEM, bending resistance (mN)	0,79	0,77
Bend index (mN x m²/g)	0,63	0,32

In the table 21 is shown bending resistance of Simcastor plus 45 g/m². As it can be seen, bending resistance and index in machine direction was about 2 times more than in cross direction. Values of standard deviation and standard error of mean were very near in both direction. (Detailed test results are listed in appendix 7).

The results of Lumiflex 80 g/m² bending resistance are listed in the table 22. Bending resistance and index were again 2 times bigger in machine direction. There was also more standard deviation in machine direction. (Detailed test results are listed in appendix 7).

Table 22. Bending resistance of Lumiflex 80 g/m².

	MD	CD
Bending resistance average (mN)	55,90	28,20
Bending resistance st. dev.(mN)	2,96	1,87
y min, bending resistance (mN)	54,18	27,11
y max, bending resistance (mN)	57,62	29,29
SEM, bending resistance (mN)	0,94	0,59
Bend index (mN x m²/g)	0,70	0,35

Bending resistance of Cupforma 170 g/m² is shown in the table 23. Bending resistance and index were over 2 times higher in machine direction. Standard deviation occurred also more in machine direction. (Detailed test results are listed in appendix 7).

Table 23. Bending resistance of Cupforma 170 g/m².

	MD	CD
Bending resistance average (mN)	65,30	30,80
Bending resistance st. dev.(mN)	2,95	1,93
y min, bending resistance (mN)	63,19	29,42
y max, bending resistance (mN)	67,41	32,18
SEM, bending resistance (mN)	0,93	0,61
Bend index (mN x m²/g)	0,38	0,18

In the table 24 is shown bending resistance of Simcote 250 g/m². Bending resistance and index are bit under 2 times higher in machine direction. Standard deviation and standard error of mean were almost equal this time. (Detailed test results are listed in appendix 7).

Table 24. Bending resistance of Simcote 250 g/m².

	MD	CD
Bending resistance average (mN)	360,60	194,30
Bending resistance st. dev.(mN)	4,58	4,52
y min, bending resistance (mN)	357,33	191,06
y max, bending resistance (mN)	363,87	197,54
SEM, bending resistance (mN)	1,45	1,43
Bend index (mN x m²/g)	1,44	0,78

In the table 25 are the results of Ensogloss 240 g/m² bending resistance. There was again almost 2 times more bending strength in machine direction while in cross direction standard deviation and SEM were almost 1,5 times bigger compared to machine direction values. (Detailed test results are listed in appendix 7).

Table 25. Bending resistance of Ensogloss 240 g/m².

	MD	CD
Bending resistance average (mN)	128,00	68,00
Bending resistance st. dev.(mN)	1,33	1,94
y min, bending resistance (mN)	127,05	66,61
y max, bending resistance (mN)	128,95	69,39
SEM, bending resistance (mN)	0,42	0,61
Bend index, (mN x m²/g)	0,53	0,28

With bending resistance the results were equal in terms of relation between machine -and cross direction as bending resistance was with each sample bit over or less 2 times more than in cross direction.

The results of bending resistance of the own sheets are listed in the table 26. Spruce had highest bending resistance and the bending resistance of pine was in the dame range. Eucalyptus had the weakest bending resistance. There was less standard deviation and standard error of mean with birch bending resistance results. (Detailed test results are listed in appendix 7).

Table 26. Bending resistance of the own sheets.

	Eucalyptus	Birch	Pine	Spruce
Bending resistance average (mN)	107,10	114,80	124,50	126,50
Bending resistance st. dev.(mN)	15,75	8,01	19,58	22,37
y min, bending resistance (mN)	95,83	109,07	110,49	110,50
y max, bending resistance (mN)	118,37	120,53	138,51	142,50
SEM, bending resistance (mN)	4,98	2,53	6,19	7,07
Bend index (mN x m^2/g)	1,34	1,44	1,56	1,58

8.3.5 Bonding strength

Bonding strength of paper and board samples was measured with the Scott bond tester -device. There is no ISO standard for the bonding strength and instructions for the test was taken from TAPPI T403 & T833 standards. The Sample Prep Station have 5 aluminum platens with a sample size of 25.4 x 25.4 mm (1.0 x 1.0 inches), so each sample was cut into 25.4 x 150 mm and extra length of the sample was cut after glued with double-sided tape. Test was repeated 10 times with each samples. In the table 27 are the results of paper mill samples bonding strength. (Detailed test results are listed in appendix 8)

Table 27. Bonding strength of paper mill samples.

	Simcastor plus 45 g/m²	Lumiflex 80 g/m²	Cupforma 170 g/m²	Ensogloss 240 g/m²	Simcote 250 g/m²
Average (J/m²)	135,30	43,20	40,60	37,70	24,00
St. dev. (J/m²)	13,09	10,46	3,27	3,71	3,65
y min (J/m²)	125,94	35,71	38,26	35,04	21,39
y max (J/m²)	144,66	50,69	42,94	40,36	26,61
SEM (J/m²)	4,14	3,31	1,03	1,17	1,15

It can be seen from the table 27 that bonding strength of papers is higher than boards. Simcastor plus had 3 times more bonding strength than Lumiflex. Cupforma and Ensogloss had bit lower bonding strength compared to Lumiflex. Simcote had notably weakest bonding strength. In this test it was clearly seen how bonding strength decreases when grammage increases.

Table 28. Bonding strength of own sheets.

	Eucalyptus	Birch	Pine	Spruce
Average (J/m²)	115,2	109,80	321,20	130,30
St. dev.(J/m²)	3,26	3,99	11,26	4,06
y min (J/m²)	112,87	106,94	313,14	127,40
y max (J/m²)	117,53	112,66	329,26	133,20
SEM (J/m²)	1,03	1,26	3,56	1,28

In the table 28 are the results of own sheets bonding strength. Pine had the highest bonding strength, birch had the weakest. Eucalyptus had bit higher bonding strength than birch. Spruce had already clearly higher bonding strength than birch and eucalyptus. (Detailed test results are listed in appendix 8)

9 SUMMARY

The aim of this thesis work was to find reference values for the most common physical paper tests. The samples were selected from the ready industrial paper and board grades and own sheets were made from birch, eucalyptus, pine and spruce pulps. Paper and board samples can be found from the paper laboratory as well as pulps used in own sheets. Tests were performed by the instructions of ISO standards as far as they were available for the test method. Other used standards were from TAPPI.

Test results in this work are supposed to give some ranges for each measured property. The ranges are defined by 95% confidence level and it gives already pretty narrow range without being too tight and allows some deviation with the results. Also the number of test repetitions were normally 10 which is too little if finding more accurate and tighter reference range. Finding the true average and true range requires a lot of test repetitions. In this work the aim was to create the basis of the reference measurements of physical properties of paper and board and results that can be reliable and accurate enough for reference values considering the used time and resources in this work. More accurate and reliable data can be achieved when more test results are gathered together with these basis reference measurements. Further development of the reference measurements would apply for creating the electronic database and testing other properties of paper and boards with more paper and board samples.

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Test: Grammage 1 (1)

Paper mill samples (200 mm x 250 mm)

	1	2	3	4	5	6	7	8	9	10
Simcastor plus	2,35	2,33	2,31	2,27	2,28	2,35	2,33	2,26	2,32	2,29
Lumiflex	3,98	3,99	3,96	3,98	4,00	3,99	3,97	3,98	3,98	3,99
Simcote	12,57	12,52	12,59	12,59	12,49	12,55	12,57	12,54	12,59	12,53
Ensogloss	11,95	11,85	11,91	11,95	11,95	11,92	11,88	11,90	11,91	11,93
Cupforma	8,44	8,37	8,34	8,43	8,44	8,42	8,43	8,36	8,39	8,41

Own sheets (310cm²)

	1	2	3	4	5	6	7	8	9	10
Birch	2,43	2,49	2,37	2,43	2,50	2,53	2,48	2,50	2,54	2,48

	11	12	13	14	15	16	17	18	19	20
Birch	2,47	2,50	2,52	2,46	2,43	2,37	2,53	2,38	2,42	2,49

	1	2	3	4	5	6	7	8	9	10
Eucalyptus	2,61	2,66	2,63	2,64	2,53	2,38	2,46	2,63	2,62	2,62

	11	12	13	14	15	16	17	18	19	20
Eucalyptus	2,59	2,64	2,62	2,63	2,67	2,65	2,59	2,37	2,58	2,55

	1	2	3	4	5	6	7	8	9	10
Pine	2,30	2,63	2,63	2,51	2,60	2,57	2,36	2,59	2,62	2,70

	11	12	13	14	15	16	17	18	19	20
Pine	2,62	2,78	2,68	2,62	2,51	2,45	2,57	2,55	2,53	2,58

	1	2	3	4	5	6	7	8	9	10
Spruce	2,48	2,57	2,57	2,55	2,49	2,53	2,49	2,60	2,50	2,61

	11	12	13	14	15	16	17	18	19	20
Spruce	2,57	2,53	2,50	2,57	2,52	2,50	2,47	2,50	2,53	2,54

Test: Moisture, oven-drying method

Simcastor plus 45 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	9,3	8,7	10,7	12,7	9,8	11,3	12	12,1	10,7	10,6

Lumiflex 90 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	7,70	9,10	8,80	10,50	9,50	8,60	9,20	8,30	9,10	9,00

Simcote 250 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	10,00	8,60	9,30	8,40	9,70	9,20	10,30	11,20	8,20	8,90

Ensogloss 240 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	6,80	6,70	8,20	7,50	7,30	8,80	7,80	7,60	6,90	7,20

Cupforma 170 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	7,80	10,30	8,30	8,50	9,30	8,20	8,20	9,40	8,70	9,70

Simcastor plus 45 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	12,2	12,7	9,7	11,8	12,5	12,0	10,2	7,2	12,4	11,2

Lumiflex 80 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	9,3	6,3	7,7	7,4	6,3	5,9	7,2	7,3	5,8	6,7

Simcote 250 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	9,20	6,30	7,10	6,20	6,70	8,80	7,90	7,40	8,50	7,40

Ensogloss 240 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	5,70	5,20	5,30	5,20	4,80	6,20	5,50	6,30	7,00	5,60

Cupforma 170 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Moisture (%)	7,60	7,40	7,00	8,10	6,50	7,20	6,60	7,10	7,20	6,80

Test: Thickness

Simcastor plus 45 g/ g/m², 8 sheet ply

Test no	1	2	3	4	5	6	7	8	9	10
Thickness (µm)	319	313	311	312	315	313	314	316	311	315

Lumiflex 80 g/m², 8 sheet ply

Test no	1	2	3	4	5	6	7	8	9	10
Thickness (µm)	653	651	650	654	653	652	651	654	656	655

Simcote 250 g/m², 1 sheet

Test no	1	2	3	4	5	6	7	8	9	10
Thickness (µm)	448	443	443	442	443	442	446	445	447	445

Ensogloss 240 g/m², 1 sheet

Test no	1	2	3	4	5	6	7	8	9	10
Thickness (µm)	304	298	305	300	299	300	296	301	296	302

Cupforma 170 g/m², 1 sheet

Test no	1	2	3	4	5	6	7	8	9	10
Thickness (µm)	212	211	208	211	212	212	214	211	209	211

Test: Tensile strength

Sample: Simcastor plus 45 g/m²

Machine direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile Force (N)	51,78	56,5	52,49	53,72	51,81	54,86	49,23	50,11	54,51	51,82
Elongation (mm)	2,08	1,84	2,20	2,15	2,20	1,69	1,85	1,96	2,20	2,07
Tensile index (Nm/g)	76,7	83,7	77,8	79,6	76,8	81,3	72,9	74,2	80,8	76,8

Machine direction 2nd serie

Test no	1	2	3	4	5	6	7	8	9	10
Tensile Force (N)	47,71	52	46,09	52,9	48,88	42,93	52,63	51,7	54,68	55,4
Elongation (mm)	2,00	2,58	1,80	2,16	2,05	1,54	1,89	2,02	1,85	2,25
Tensile index (Nm/g)	70,7	77,0	68,3	78,4	72,4	63,6	78,0	76,6	81,0	82,1

Test no	11	12	13	14	15
Tensile Force (N)	60,48	56,24	43,82	54,9	56,02
Elongation (mm)	2,03	1,88	1,50	1,88	2,16
Tensile index (Nm/g)	89,6	83,3	64,9	81,3	83,0

Cross direstion

Test no	1	2	3	4	5	6	7	8	9	10
Tensile Force (N)	18,75	20,78	20,66	19,89	19,19	19,7	19,58	19,84	20,56	22,04
Elongation (mm)	4,27	6,03	5,75	6,89	5,60	5,36	5,49	5,07	6,34	6,88
Tensile index (Nm/g)	27,8	30,8	30,6	29,5	28,4	29,2	29,0	29,4	30,5	32,7

Cross direction 2nd serie

Test no	1	2	3	4	5	6	7	8	9	10
Tensile Force (N)	20,69	19,94	20,35	21,05	20,34	20,19	20,5	21,25	21,63	20,35
Elongation (mm)	6,19	5,99	5,57	6,19	5,91	5,57	6,40	5,90	5,58	4,69
Tensile index (Nm/g)	30,7	29,5	30,1	31,2	30,1	29,9	30,4	31,5	32,0	30,1

Test no	11	12	13	14	15
Tensile Force (N)	21,74	20,5	21,68	20,97	20,73
Elongation (mm)	6,45	5,28	6,01	5,86	5,07
Tensile index (Nm/g)	32,2	30,4	32,1	31,1	30,7

Test: Tensile strength

Sample: Lumiflex 80 g/m²

Machine direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile strength (N)	96,05	99,99	94,07	78,23	87,88	98,06	97,33	95,28	97,87	97,30
Elongation (mm)	2,34	2,61	2,54	1,86	2,35	2,57	2,59	2,34	2,56	2,60
Tensile index (Nm/g)	80,04	83,33	78,39	65,19	73,23	81,72	81,11	79,40	81,56	81,08
Tensile index average	78,51									
Standard deviation	5,42									

Cross direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile strength (N)	35,83	38,77	35,67	37,37	36,10	31,91	37,55	37,89	36,20	38,48
Elongation (mm)	4,91	5,86	4,72	5,20	4,83	3,80	5,70	5,31	5,21	5,01
Tensile index (Nm/g)	29,86	32,31	29,73	31,14	30,08	26,59	31,29	31,58	30,17	32,07
Tensile index average	30,48									
Standard deviation	1,65									

Test: Tensile strength

Sample: Simcote 250 g/m²

Machine direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N/mm)	18,70	17,95	18,39	18,45	18,81	19,01	19,05	18,62	18,28	18,38
Elongation (mm)	2,55	2,08	1,92	1,77	1,78	2,11	1,91	1,74	1,92	1,87
Tensile index (Nm/g)	5,19	4,99	5,11	5,13	5,23	5,28	5,29	5,17	5,08	5,11
Tensile index average	5,16									
Standard deviation	0,09									

Cross direction

Test no	1,00	2,00	3,00	4,00	5,00	6,00	7,00	8,00	9,00	10,00
Tensile force (N/mm)	12,12	11,83	11,83	11,60	12,41	12,31	12,51	12,14	11,31	11,88
Elongation (mm)	4,30	3,63	3,85	3,38	4,04	3,88	3,97	4,36	3,47	3,99
Tensile index (Nm/g)	3,37	3,29	3,29	3,22	3,45	3,42	3,48	3,37	3,14	3,30
Tensile index average	3,33									
Standard deviation	0,10									

Test: Tensile strength

Sample: Cupforma 170 g/m²

Machine direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N/mm)	28,55	27,87	28,08	28,04	28,80	27,87	28,60	27,72	28,38	28,47
Elongation (mm)	2,63	2,58	2,76	2,58	2,60	2,38	2,78	2,56	2,77	2,76
Tensile index (Nm/g)	11,20	10,93	11,01	11,00	11,29	10,93	11,22	10,87	11,13	11,16
Tensile index average	11,07									
Standard deviation	0,14									

Cross direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N/mm)	12,80	13,35	13,07	13,50	13,13	12,96	13,23	12,93	13,01	13,40
Elongation (mm)	6,64	7,04	6,69	7,08	7,04	6,85	6,88	6,69	6,57	7,08
Tensile index (Nm/g)	5,02	5,24	5,13	5,29	5,15	5,08	5,19	5,07	5,10	5,25
Tensile index average	5,15									
Standard deviation	0,09									

Test: Tensile strength

Sample: Ensogloss 240 g/m²

Machine direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N)	29,76	27,92	27,44	27,95	28,74	28,65	28,37	28,16	29,90	27,69
Elongation (mm)	3,09	2,96	2,99	3,30	3,07	3,09	3,04	3,11	3,10	3,12
Tensile index (Nm/g)	8,27	7,76	7,62	7,76	7,98	7,96	7,88	7,82	8,31	7,69
Tensile index average	7,91									
Standard deviation	0,23									

Cross direction

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N)	17,81	18,59	18,75	19,01	18,04	18,22	18,77	18,67	17,67	17,74
Elongation (mm)	6,52	6,95	7,16	7,25	6,46	6,82	7,05	7,46	6,71	6,62
Tensile index (Nm/g)	4,95	5,16	5,21	5,28	5,01	5,06	5,21	5,19	4,91	4,93
Tensile index average	5,09									
Standard deviation	0,14									

Eucalyptus 80 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N)	34,05	30,37	31,97	29,66	31,68	31,68	29,64	30,54	31,54	32,70
Elongation (mm)	1,54	1,33	1,35	1,33	1,34	1,34	1,29	1,35	1,49	1,56
Tensile index (Nm/g)	28,38	25,31	26,64	24,72	26,40	26,40	24,70	25,45	26,28	27,25
Tensile index average	26,15									
Standard deviation	1,15									

Birch 80 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N)	31,75	31,05	38,88	36,54	32,88	33,35	33,40	35,60	35,86	33,77
Elongation (mm)	1,34	1,53	1,64	1,32	1,25	1,21	1,21	1,36	1,48	1,41
Tensile index (Nm/g)	26,46	25,88	32,40	30,45	27,40	27,79	27,83	29,67	29,88	28,14
Tensile index average	28,59									
Standard deviation	1,99									

Pine 80 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N)	55,02	50,38	46,24	54,81	51,77	52,26	60,30	53,93	58,57	52,47
Elongation (mm)	2,55	2,06	2,18	3,19	2,74	3,02	3,21	2,69	3,05	3,11
Tensile index (Nm/g)	45,85	41,98	38,53	45,68	43,14	43,55	50,25	44,94	48,81	43,73
Tensile index average	44,65									
Standard deviation	3,33									

Spruce 80 g/m²

Test no	1	2	3	4	5	6	7	8	9	10
Tensile force (N)	30,32	30,96	34,87	29,90	33,93	34,12	33,74	32,84	36,31	36,95
Elongation (mm)	1,52	1,53	1,49	1,15	1,70	1,57	1,36	1,53	1,67	1,46
Tensile index (Nm/g)	25,27	25,80	29,06	24,92	28,28	28,43	28,12	27,37	30,26	30,79
Tensile index average	27,83									
Standard deviation	2,01									

Test: Bursting strength

Paper mill samples

Test no.	Simcastor plus 45 g/m²	Lumiflex 80 g/m²	Simcote 250 g/m²	Cupforma 170 g/m²	Ensogloss 240 g/m²
1	139	245	369	785	988
2	150	245	402	781	986
3	140	253	426	754	984
4	141	251	404	813	956
5	140	239	451	805	994
6	131	247	422	815	917
7	143	252	391	769	998
8	125	262	427	773	934
9	139	241	440	772	925
10	144	260	430	720	932

Own sheets 80 g/m²

Test no.	Eucalyptus	Birch	Pine	Spruce
1	117	112	305	129
2	117	108	327	125
3	115	108	343	130
4	114	113	308	133
5	112	116	317	138
6	115	113	333	130
7	109	108	322	132
8	120	102	317	124
9	114	111	323	129
10	119	107	317	133

Test: Tearing resistance

Sample: Simcastor plus 45 g/m², 10 sheets ply

Machine direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	137	144	150	137	141	140	149	146	151	139
Tear index (mN·m²/g)	3,04	3,20	3,33	3,04	3,13	3,11	3,31	3,24	3,36	3,09

Cross direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	195	179	179	176	184	180	191	177	171	183
Tear index (mN·m²/g)	4,33	3,98	3,98	3,91	4,09	4,00	4,24	3,93	3,80	4,07

Test: Tearing resistance, 4 sheet ply

Sample: Lumiflex 80 g/m²

Machine direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	465	472	465	457	465	467	455	470	468	460
Tear index (mN·m²/g)	5,8	5,9	5,8	5,7	5,8	5,8	5,7	5,9	5,9	5,8

Cross direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	606	560	614	575	622	570	610	586	602	591
Tear index (mN·m²/g)	7,6	7,0	7,7	7,2	7,8	7,1	7,6	7,3	7,5	7,4

Test: Tearing resistance

Sample: Cupforma 170 g/m², single sheet 2 (2)

Machine direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	1486	1448	1492	1513	1571	1456	1488	1507	1542	1455
Tearing index (mN·m²/g)	8,74	8,52	8,78	8,90	9,24	8,56	8,75	8,86	9,07	8,56

Cross direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	1576	1419	1470	1556	1481	1492	1529	1497	1514	1472
Tearing index (mN·m²/g)	9,27	8,35	8,65	9,15	8,71	8,78	8,99	8,81	8,91	8,66

Test: Tearing resistance

Sample: Ensogloss 240 g/m², single sheet

Machine direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	1865	1908	1894	1950	1894	1908	1908	1781	1964	1880
Tear index (mN·m²/g)	7,77	7,95	7,89	8,13	7,89	7,95	7,95	7,42	8,18	7,83

Cross direction

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	2046	2087	2005	2182	2046	1822	1879	2195	2214	2155
Tear index (mN·m²/g)	8,53	8,70	8,35	9,09	8,53	7,59	7,83	9,15	9,23	8,98

Test: Tearing resistance

Sample: Simcote 250 g/m², single sheet

Simcote 250 g/m² MD

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	1403	1410	1379	1475	1475	1465	1442	1442	1345	1472
Tear index (mN·m²/g)	5,61	5,64	5,52	5,90	5,90	5,86	5,77	5,77	5,38	5,89

Simcote 250 g/m² CD

	1	2	3	4	5	6	7	8	9	10
Tearing resistance (mN)	1957	2178	2052	2272	2020	2396	2241	2052	2147	1989
Tear index (mN·m²/g)	7,83	8,71	8,21	9,09	8,08	9,58	8,96	8,21	8,59	7,96

Test: Bending resistance, 15ˀ 5 mm

Sample: Paper mill papers

Simcastor plus 45 g/m² MD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	25,0	29,0	29,0	29,0	33,0	30,0	26,0	29,0	25,0	30,0

Simcastor plus 45 g/m² CD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	12,0	12,0	16,0	16,0	12,0	16,0	13,0	11,0	16,0	18,0

Lumiflex 80 g/m² MD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	55,0	55,0	59,0	55,0	50,0	60,0	57,0	55,0	59,0	54,0

Lumiflex 80 g/m² CD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	29,0	25,0	29,0	29,0	29,0	30,0	27,0	25,0	30,0	29,0

Test: Bending resistance, 15× 50 mm

Sample: Paper mill boards

Cupforma 170 g/m² MD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	65,0	70,0	65,0	65,0	65,0	60,0	63,0	65,0	70,0	65,0

Cupforma 170 g/m² CD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	30,0	30,0	33,0	30,0	30,0	35,0	30,0	29,0	29,0	32,0

Simcote 250 g/m² MD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	357,0	364,0	369,0	363,0	356,0	359,0	361,0	355,0	365,0	357,0

Simcote 250 g/m² CD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	198,0	193,0	185,0	198,0	193,0	190,0	195,0	200,0	198,0	193,0

Ensogloss 240 g/m² MD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	128,0	128,0	128,0	128,0	129,0	129,0	125,0	128,0	130,0	127,0

Ensogloss 240 g/m² CD

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	69,0	69,0	69,0	69,0	64,0	70,0	69,0	68,0	65,0	68,0

Test: Bending resistance, 15°/ 10 mm

Sample: Own sheets 80 g/m²

Eucalyptus

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	90,0	89,0	136,0	101,0	122,0	97,0	101,0	110,0	100,0	125,0

Birch

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	131,0	113,0	104,0	117,0	117,0	111,0	103,0	115,0	117,0	120,0

Pine

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	95,0	150,0	136,0	99,0	113,0	110,0	140,0	123,0	132,0	147,0

Spruce

	1	2	3	4	5	6	7	8	9	10
Bending resistance (mN)	103,0	136,0	99,0	118,0	170,0	145,0	110,0	123,0	115,0	146,0

Test: Bonding strength

Sample: Paper mill samples 1 (1)

Test no.	Simcastor plus 45 g/m² (J/m²)	Lumiflex 80 g/m² (J/m²)	Cupforma 170 g/m² (J/m²)	Ensogloss 240 g/m² (J/m²)	Simcote 250 g/m² (J/m²)
1	150	50	38	39	23
2	150	62	42	39	26
3	122	37	42	38	25
4	148	32	43	31	25
5	140	59	45	38	20
6	113	40	45	35	22
7	134	33	36	35	22
8	125	42	38	36	33
9	144	41	37	42	22
10	127	36	40	44	22

Test: Bonding strength

Sample: Own sheets 80 g/m²

Test no.	Eucalyptus (J/m²)	Birch (J/m²)	Pine (J/m²)	Spruce (J/m²)
1	117	112	305	129
2	117	108	327	125
3	115	108	343	130
4	114	113	308	133
5	112	116	317	138
6	115	113	333	130
7	109	108	322	132
8	120	102	317	124
9	114	111	323	129
10	119	107	317	133

List of standards used at work

- Preparation of laboratory sheets for physical testing - Part 2: Rapid-Köthen method - ISO 5269 -1:1998(E)
- Determination of grammage – ISO 536:1995(E)
- Determination of moisture – oven-drying method – ISO 287-1985(E)
- Determination of thickness, density and specific volume - ISO 534:2005 (E)
- Determination of tensile properties - ISO 1924 - 1:1992(E)
- Determination of bursting strength - ISO 2758:1983(E)
- Determination of tearing resistance (Elmendorf method) - ISO 1974:1990(E)
- Determination of bending resistance - ISO 2493:1992
- Determination of bonding strength - TAPPI T403 & T833