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**Measurement of TMP properties based
on NIR spectral analysis**

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University of Oulu
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Abstract: This report discusses a NIR analysis application of Thermomechanical pulp (TMP) properties measured with a TQA analyzer. TQA (Total Quality Analyzer) is ABB's measurement device that measures in-line the NIR spectra from the pulp flowing through the blow line of a TMP process. The main purpose of this work was to measure the freeness, strength properties (tear index, tensile index) and light scattering coefficient of the pulp using the NIR spectra. Data for the calibration of the measurements was collected during several test runs in a Finnish TMP plant. The calibrated measurements were also tested with independent test data. The calibration was done using the Partial Least Squares method.

Furthermore, the NIR spectra were measured from the hand sheets made for the laboratory analysis using a laboratory FT-IR analyzer. Correlations between the spectral analysis and several pulp characteristics were studied.

KEYWORDS: NIR analysis, Partial Least Squares, Modelling, Tensile index, Freeness, Thermomechanical pulping

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1 INTRODUCTION

Near InfraRed (NIR) Spectroscopy is a measurement technology, which opens new possibilities to characterise different quality parameters from the pulp. No single technique can solve all measurement needs of the pulp, but NIR spectral analysis can offer several advantages over conventional analysis and instrumental methods used in the industry. Although used in laboratory applications e.g. in food industry for some years, its use in process instruments has still been almost non-existent. However, the recent development in NIR spectral detectors, other optical components and calibration methods has introduced reliable solutions, which can be applied to industrial process instruments, too.

Some research work of NIR Spectroscopy applications in pulp and paper industry has been reported (see for example *Furumoto et al*, 2000, *Antti & Sjöström*, 1996, *Olsson et al*, 1995). These applications are mainly for chemical pulp or cooking liquor; and usually NIR spectra are measured in the laboratory from pulp samples or laboratory hand sheets. *Karlsson & Wancke* (2000) have reported an on-line NIR-measurement application in a TMP plant. This application measures spectra from the wood chips before the refiners. So far, no on-line applications that measure the NIR spectra directly from the refined pulp have been reported.

TQA is an advanced analyser that performs a continuous in-line measurement of several variables from the pulp flowing through the blow line of a TMP process. The basic TQA measurements include consistency, freeness and fines. The measurements of hand sheet properties (tensile index, tear index and light scattering coefficient) are investigated in this report.

This report discusses the measurement application; calibration and sampling issues as well as achieved performance of the analyser in a Finnish TMP plant. In addition, in-line TQA NIR measurements and laboratory NIR measurements are compared.

2 PROCESS DESCRIPTION

In thermomechanical pulping (TMP) preheated wood chips are refined between two discs. Typically, the chips are refined in two stages (Figure 1). First, the chips are fed into the primary refiner. This stage is usually pressurised, and the refining consistency is typically from 40 to 50%. From the primary refiner pulp and steam are blown into a cyclone, where they are separated. In the secondary refiner, refining continues and the consistency is usually from 30 to 40%. After the second stage pulp and steam are blown to another cyclone for separation. Next, pulp is diluted with hot water to the consistency 2–5%. Typically, the steam pressure in the TMP process is 3–5 bars, and the temperature is 140–155 °C.

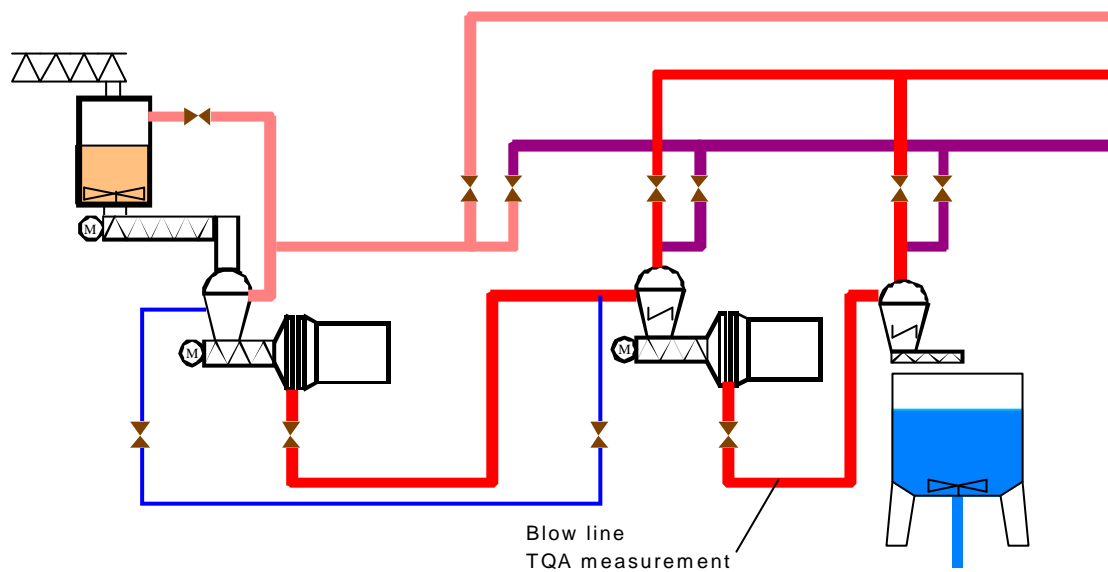


Figure 1. Thermomechanical pulping process.

Typically, the basic quality of the TMP pulp is expressed by its freeness value. It describes the water retention of the pulp, and it is usually measured in the laboratory. Normally, the freeness is controlled by the consistency and specific energy consumption. Other important properties of TMP are the fibre length, fibre fractions, tensile and tear index and light scattering coefficient.

3 TQA QUALITY ANALYZER

3.1 Measurement device

TQA (Figure 2) is an advanced analyser especially designed for the measurements in the high consistency refiner lines. Its measurement principle is based on the measurement of infrared light absorption spectra in the Near InfraRed (NIR) range. The spectrum contains both chemical and physical information of the material, which can be uncovered by spectral analysis. Although the NIR spectral analysis is a novel measurement method in industrial analyser applications, the research work and laboratories have known it for years.

NIR spectrometry (wavelength bands 800–2400 nm) is an analytical method to measure the absorption of near infrared light in materials. Light is composed of electric and magnetic waves that travel through space. Further, molecules and ions have the ability to absorb infrared light, and the frequency of the absorbed light corresponds to particular energy levels of inter-atomic bonds of the molecule. This fact establishes a relationship between the wavelengths and molecule structure. Thus, the molecule structures can be identified enabling the properties of the material to be qualified. I.e. the NIR spectrum is quite specific to each material and, in this case, it describes the fingerprint of pulp.

TQA performs a continuous in-line measurement of several variables from pulp flowing through the blow line of a TMP process. The basic TQA measurements include consistency, freeness, fines, and fibre fractions of the pulp. A good potential to include other measurements such as tensile strength and light scattering exists, too.

The measurements are determined by means of reflection of several specified wavelengths of infrared light in the pulp stream. The light is conducted from the light source to the blow line and further to the multi-wavelength array detector through fibre optic cables. The array detector records all the wavelengths simultaneously.



Figure 2. Measurement device.

The TQA can be installed in the blow line directly after the refiner providing continuous in-line information rapidly after the refining process. The TQA sensor head is connected to the blow line with a specific interface unit. The sensor head can be dismounted and inserted while the process is in operation.

3.2 TQA calibration

Typically, the calibration procedure involves obtaining 20–50 pulp samples at different consistencies, with different freeness and fibre fractions and production rates. The data obtained should cover the complete normal operating range of the refiner. Therefore, the actual number of required samples depends on different wood species used, number of produced grades, and which measurements are included. E.g. for the consistency only the number of samples is 15–30. The laboratory results are entered into the TQA calibration PC using dedicated calibration toolset displays. Then multivariate calibration methods (CPRC meaning Correlation Principal Component Regression and PLS meaning Partial Least Squares) are used to calibrate the sensor according to the laboratory values. During the normal operation, sensor and calibration can be quickly checked using a so-called reference reflector calibrator and TQA displays.

TQA calibration with CPRC and PLS also makes it possible to improve the calibration by adding or deleting samples thus avoiding the work required for a complete set of samples. This feature brings extra flexibility, for example when extending the operation range of some measurement. TQA calibration software includes also versatile tools and displays to analyse the spectral and laboratory data as well as data logging possibilities. Furthermore, the TQA supports remote calibration and analysis services from the support centre.

A standardised procedure for sample taking and sample handling should be used with the system. Especially, sample taking shall be executed carefully, because it typically causes the biggest errors in calibration.

4 PLS MODELLING

4.1 Partial Least Squares Method

NIR data (spectra) is usually highly collinear, thus traditional modelling methods such as Multiple Linear Regression (MLR) methods are useless when predicting chemical properties from the spectra. The collinearity problem can be avoided by Partial Least Squares (PLS) method (*Geladi & Kowalski, 1986*). In the PLS method original data is compressed on to a few latent variables (principal components). The PLS method produces a regression model between the predictor (spectra) variables and predicted variables. Main advantage of PLS is that the number of samples can be lower than the number of spectral channels.

Successful implementation of PLS is based on data pre-processing, outlier detection and selection of optimum number of latent variables (*Martens & Naes, 1989*). The validation of a PLS model can be done either by using external validation or internal validation.

4.2 Data analysis

Data analysis is the first step of the PLS modelling, and it is the most important stage in the analysis of NIR spectra (*Sun, 1997*). Data analysis includes data pre-processing and outlier detection. Data pre-processing may include scaling of data and data transform. Mean centering and variance scaling can be used in scaling. In spectroscopy, where all variables (spectra) have same units, variance scaling is not necessarily needed.

If the direct spectral absorbency values are used the PLS modelling usually fails. Thus, the spectral data must be linearly transformed. For example, logarithmically transformed or Kubelka-Munk transformed values of spectra can be used. Kubelka-Munk transformation can be calculated by the following equation:

$$R_{KM} = (1-R^2)/2R, \quad (1)$$

Where R is the absorbency value and R_{KM} is the transformed value

Outlier detection means that abnormal or erroneous values of data are removed from the calibration data, because outliers may decrease the prediction capability of the model. The outliers are caused by abnormal process situations, errors of laboratory analysis, careless sampling or errors in the spectra. They can be detected by the visual inspection of data or by using some index that is calculated for each sample, and if it exceeds some limit value, there is some abnormality in this sample. However, this is not necessarily an indication of an erroneous value. Therefore, it should be always checked if the detected sample includes some useful information, and if it does that should be included in the calibration data set. In addition, the test data should be checked for possible outliers.

Studentised residual, Cook's distance and leverage values of samples are often used in the outlier detection. Drawing the influence plot (studentised residual vs. leverage) helps to detect outliers having high leverage value and/or large studentised residual value. A large leverage value and large studentised residual value may indicate that the sample is an outlier.

4.3 Model validation

Internal validation is usually done with cross validation, and it is suitable for evaluating the model structure i.e. the number of latent variables. The external validation is based on new objects, which are not included in the calibration set. It tests the prediction ability of the model, which is the real measure of the goodness of the model. It can be evaluated by the correlation coefficient between the laboratory values and the values calculated by the model. Also, the Root Mean Square (RMS) error between the laboratory values and values calculated by the model is used in the evaluation of the model. Both indexes should be used simultaneously. These indexes are calculated for the calibration data and for the independent test data. Increasing the number of latent variables increases the correlation between the calibration and testing data and decreases the RMS error. After some optimum number of latent variables, the correlation starts to decrease and RMS error increases for the test data. The optimum number of latent variables depends on how many samples are available for the calibration. Usually, two to four latent variables are used in the calibration.

4.4 Sampling & calibration

The success of the calibration depends also how well the sampling is done, so special attention should be paid to the pulp sampling. Because rather small amount of pulp is taken from the blow line, the sample should be as homogenous as possible. In addition, the position of the sample valve should be chosen so that the flow in the blow line is turbulent. Any extra particles, moisture or pulp from the previous sampling etc. in the sample can or in the sampling valve may cause errors to the laboratory results. Thus the sampling can and sampling valve must be cleaned and dried properly after each sampling.

5 MILL EXPERIMENTS

5.1 Mill trials

TQA was installed in the blow line after the secondary stage refiner. The refiner type was a 15 MW Sunds CD 70 refiner. Chips used were Nordic spruce.

Samples for the calibration were gathered during test runs, which covered three days from May to June 2000. Ten samples were collected per day (total number of calibration samples was 30). The first test sample set (10 samples) was gathered during a two-week period in November 2000. The second test sample set (10 samples) was gathered during three weeks in December 2000. All the pulp characteristics studied were analysed from the test data sets No 1 and 2. The blow line sampler was changed to another type between the two data sets collection in November 2000. This change greatly affected the consistency analysis and, to some extent, also the freeness. Next, two additional data sets were collected in February – March 2001. The test set No 3 included 26 and test set No 4 included 12 samples. The consistency and freeness were analysed from the test data sets No 3 and 4.

All the test samples were collected during normal process operation. When a sample was taken, the spectra measured by TQA were stored automatically in the system PC. The samples were later analysed in the Mechanical Process Engineering Laboratory, in University of Oulu.

During the test runs TMP operation was changed so that it covered adequate variations in the TMP properties; i.e. the freeness, consistency, tear index, tensile index, light scattering coefficient and fibre length. The process was run at various operating points, which were defined by the limit values of the normal process operation. Usually, the limits are defined as upper and lower limit values of the consistency and freeness (Figure 3). The dilution water, plate gap, saw mill chip ratio, specific energy consumption and production rate were manipulated during the tests. The required changes were made both to the primary and secondary stage refiner. The samples were taken when the process was at its operating point. The principle of the test runs is presented in Table 1.

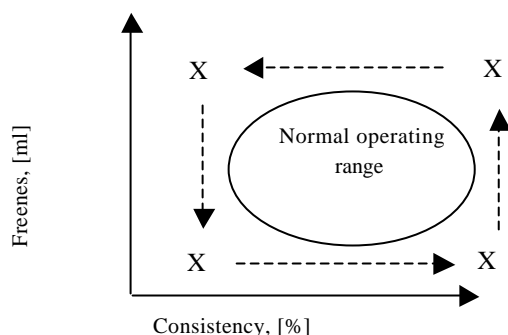


Figure 3. The operating points (marked with X) of the test runs.

Table 1. The principle of the test runs in the first day.

Operating Point	1 st stage SEC*	2 nd stage SEC*	1 st stage consistency	2 nd stage consistency	Production rate
1	+	+	+	+	+
2	+	-	+	+	+
3	+	-	-	-	+
4	-	-	-	-	+
5	-	+	-	-	+
6	-	+	+	+	+
7	+	+	+	+	-
8	+	-	+	+	-
9	+	-	-	-	-
10	-	+	-	-	-

* SEC is Specific Energy Consumption. + is high level, - is low level

5.2 Sample collection & laboratory analysis

First, the collected samples were cooled and stored in a refrigerator. Next, the samples were moved to the analysis laboratory, where the pulp properties (consistency, freeness, fibre fractions, fibre length and sheet properties) were determined by laboratory technicians. The hand sheets were prepared with a sheet mold with backwater. All the laboratory analyses, including sheet properties, were made according to SCAN standards. The following apparatus were used to analyse the results: freeness L&W App30 Type 6-1, tear strength L&W tearing tester, tensile strength L&W tensile strength tester, and light scattering coefficient Minolta CM 525i device.

6 RESULTS AND DISCUSSION

Examples of TQA NIR spectrum measurements are presented in Figures 4 and 5.

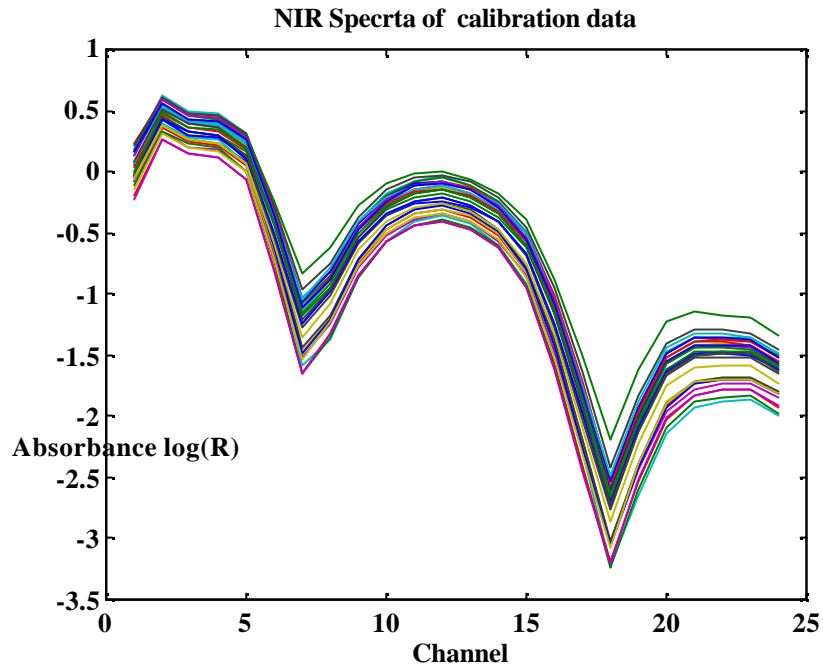


Figure 4. TQA NIR spectra of the calibration data (samples 1–30).

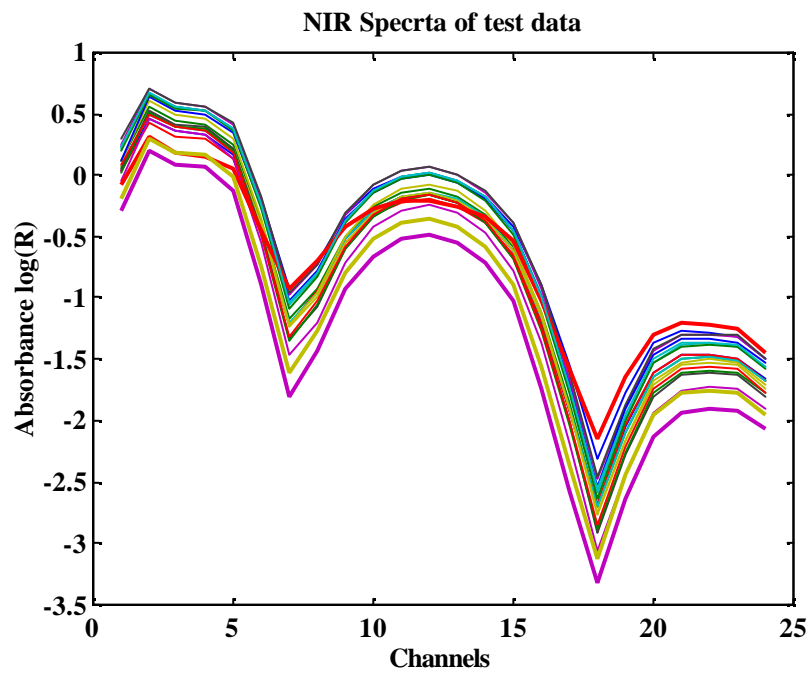


Figure 5. TQA NIR spectra of the test data (samples 31–50).

6.1 Calibration data analysis

First, the spectral data was transformed using logarithmic values. Next, the pre-processed spectra and samples were detected for possible outliers. As the figure 4 illustrates the spectra of the calibration samples (samples 1–30) do not differ significantly, and after analysing the data only one calibration sample was rejected.

The first test data sets (Sets No 1 and 2; samples 31–50) included three possible outliers after checking the spectra. Figure 5 shows that three curves in the spectra differ significantly from the others. These spectrum curves represent sample numbers 47, 48 and 49 (drawn with a bold curve in Figure 5). These samples are considered as outliers. It is possible that there has been some defect during the measurement of the spectrum, in the sampling or the operation point of the process has been abnormal. The sample number 38 was also detected as an outlier when checking the laboratory results. This sample has abnormal values in the fibre length and consistency and thus it represents abnormal process conditions. Due to this, the sample was outside the calibration range, and thus it was considered as an outlier, too. After outlier detection 29 samples were used for the calibration and 16 samples were used for the testing. The test data sets No 3 and 4 (samples 51–77 and 78–90) were analysed separately. The data set No 3 included no outliers and the data set No 4 only one, meaning that 37 samples were used for testing from these data sets. In the following analysis only the test sets 1 and 2 are studied, and they are combined as one test set.

A useful method is also to check the score plots of PLS models. Scores relate to the samples (spectra) and show how they relate to the principal components (latent variables). By plotting the scores of the spectra against the first two principal components (PC), scores (spectra) that differ significantly from the others can be found. Thus, malfunctions in the spectra can be detected. Two principal components (latent variables) were used in these models. The figure 6 shows scores of the first PC vs. scores of the second PC.

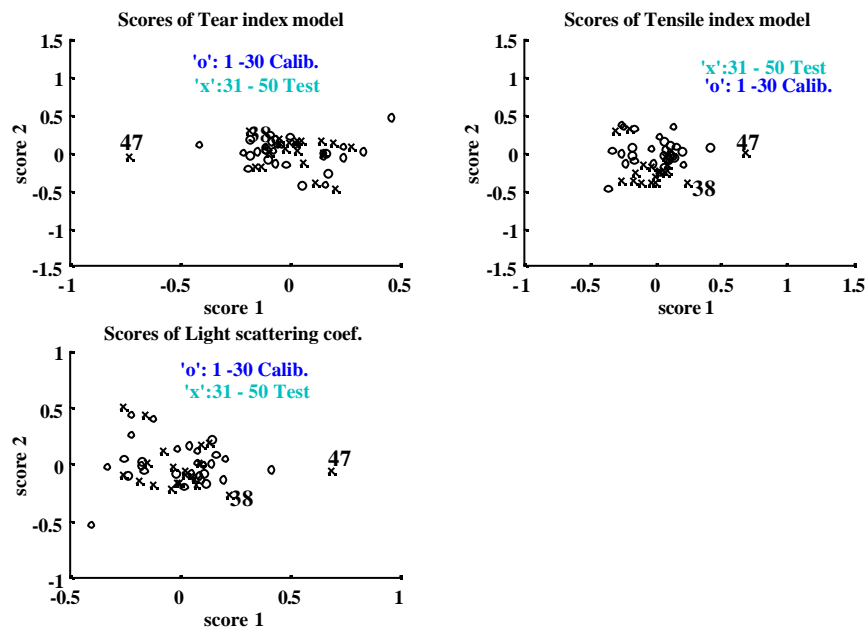


Figure 6. The score plots of the calibration and test data.

In the figure 6, the scores of the samples 38 and 47 (found as outliers before) are marked with the respective number. As the figure illustrates the scores of the sample 47 is far away from the others. All the scores should locate at the same region. Scores that locate far outside this region should be considered as possible outliers. Scores of the sample 38 do not differ from the others. There was no abnormality in its spectra. However, checking of the laboratory data proved it is as an outlier.

After the outlier detection, the transformed spectra and the values of the laboratory analyses were used to obtain regression models using the PLS method. The model structures (the optimum number latent variables) were determined from previous experience. Two latent variables were used for all the models.

6.2 Consistency and freeness

TQA development is based on the TCA (TMP Consistency Analyzer), which has been applied to refiner lines for consistency measurement and control. In the previous work also the freeness and different fibre class analysis were measured with TQA. In this study the consistency and freeness were further studied.

Naturally, the consistency results (Figure 7) were similar as in the previous studies. The achieved correlation between the laboratory and TQA measurement was very high (>0.97). The consistency measurement is discussed more e.g. in the reference [9].

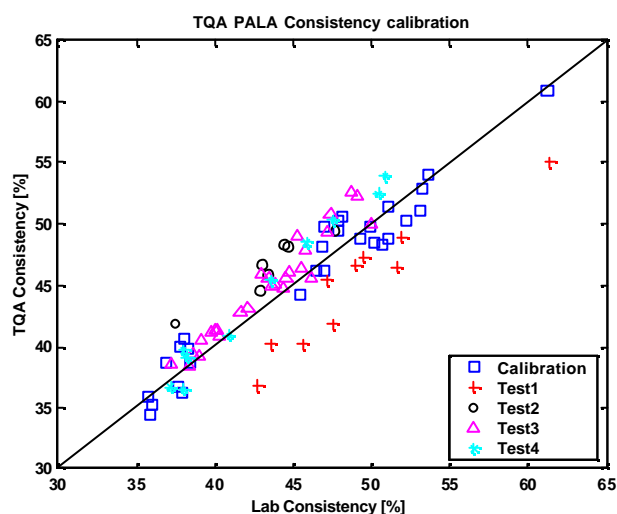


Figure 7. TQA consistency vs. laboratory consistency

Also, the freeness measurement showed a good correlation with the laboratory analyses. The results are presented in the figure 8. The effect of the blow line sampler change can be observed as an offset change in the figure 8a. The samples from the old sampler (calibration set and test set No 1) make clearly a separate group compared to the samples from the new sampler (test sets No 2, 3 and 4). When this offset ca. 20 ml is corrected (Figure 8b) all the test samples fit well on the calibration line. It shall also be noted that the test samples above 170 ml are outside the calibration range. A correct calibration should of course cover the whole range of the test data. It would

improve the correlation further. The SEP (Standard Error of Prediction) values were 17, 11, 8 and 11 ml in the tests 1, 2, 3 and 4, respectively. In this case SEP is the root mean square of the difference between the laboratory analysis and TQA measurement. Thus it indicates the accuracy of the measured value.

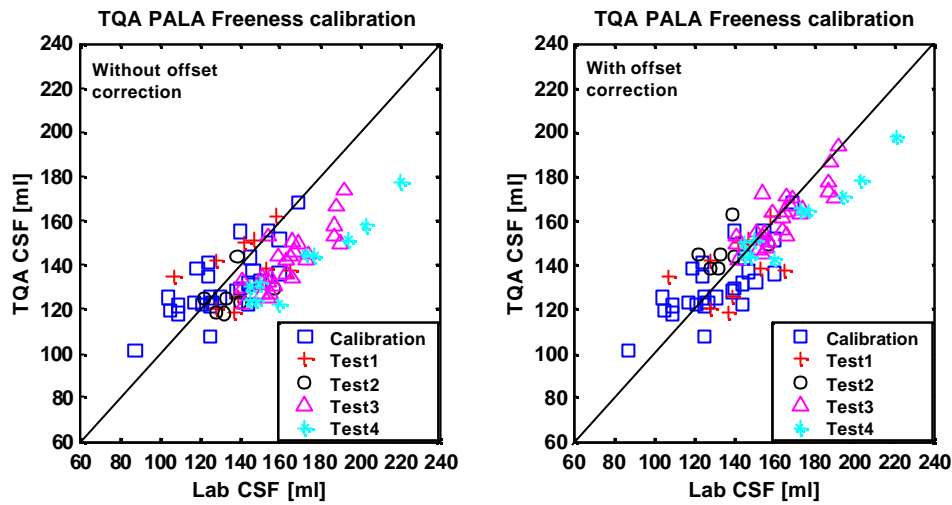


Figure 8. TQA freeness vs. laboratory freeness
 8a. Without the offset correction
 8b. With the offset correction

6.3 Tensile index

The results of the calibration and testing of the tensile index are presented in the figure 9b. The figure shows laboratory vs. measured values of the calibration and testing. As the figure illustrates the measured results are very good representing measurement accuracy close to the laboratory accuracy. The SEP values are 1,2 and 1,3 kNm/kg in the tests 1 and 2.

6.4 Tear index

The results of the tear index are presented in the figure 9c. As expected, the results are not as good as for the tensile index. One reason is that the calibration data was from too narrow operating range; from 7.7 to 8.63 mNm²/g. Because the range was this small the calibration algorithm couldn't work properly. The variation should be at least about $\pm 10\%$ around the mean. It was not possible to make a wider range with this refiner and raw material during the mill experiments. Moreover, when this process is in normal operation, tear index is very stable.

6.5 Light scattering coefficient

The results of the light scattering coefficient are presented in the Figure 9d. The calibration algorithm was reasonable good, but again the test data range was too narrow to reliably verify the results. Test data was also partly outside the calibration area. The SEP values were 0,7 and 0,8 m²/kg in the tests 1 and 2. However, good possibilities

to measure also the light scattering coefficient are expected based on earlier experiences and light scattering theory.

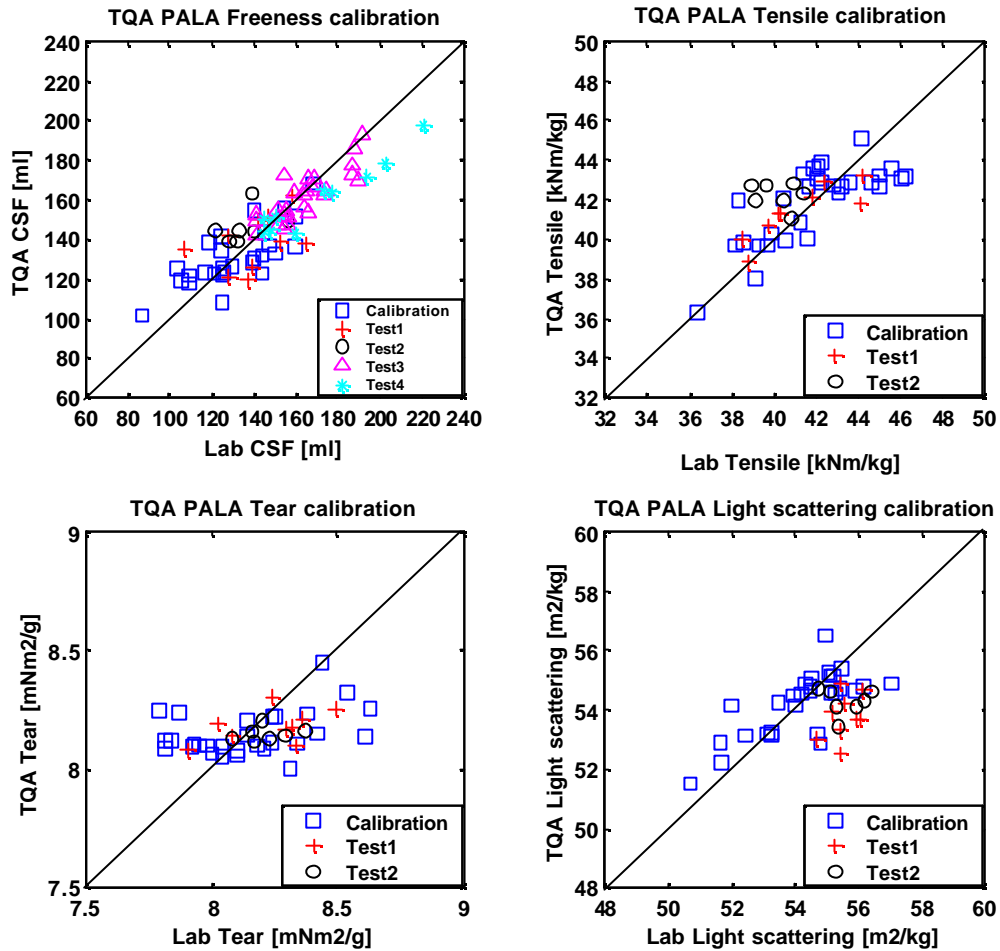


Figure 9. The correlation plot of the measured (TQA) vs. laboratory values:
 9a. Freeness,
 9b. Tensile index,
 9c. Tear index,
 9d. Light scattering coefficient

6.6 TQA consistency and freeness measurements in long term

TQA consistency and freeness measurements were monitored also during normal operation in long term. Figures 10 and 11 show a comparison between the TQA on-line consistency and freeness measurements and the results from the so-called shift samples analysed at the mill. Due to the modification of the blow line sampler in November 2000 there is about 6% systematic error between TQA and mill laboratory consistency. It can clearly be seen in the trend plots. The exact effect of the new sampler on the freeness analysis is unknown, but because the effect on the consistency level was this clear some error in the freeness is evident as well. As discussed earlier, also comparing the calibration and test set No1 (old sampler) to the test sets No 2, 3 and 4 (new sampler) in Figure 8 a 20 ml offset error can be observed.

Furthermore, because the analyses for these trend plots were done in a different laboratory using different analysis apparatus than the analyses for the xy plots (Figures 7–9), there is some additional offset in the results (i.e. between the TQA calibration samples, which were analysed in the university laboratory and these follow-up samples analysed in the laboratory at the mill). However, the magnitude of this offset was not studied and not corrected in the trend plots.

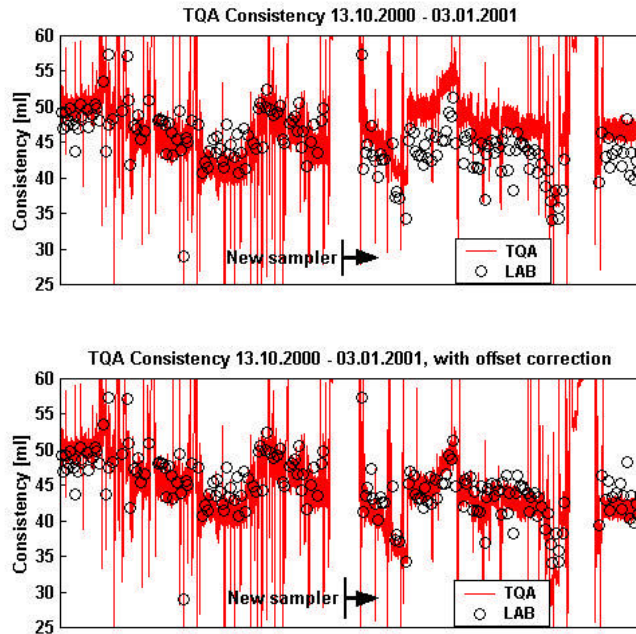


Figure 10. TQA and shift laboratory measurements of the consistency.

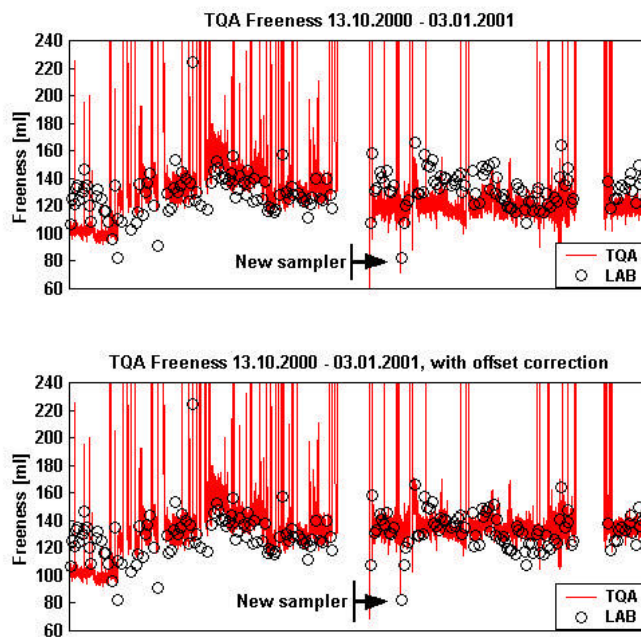


Figure 11. TQA and shift laboratory measurements of the freeness.

7 MEASUREMENT OF THE NIR SPECTRA FROM HAND SHEETS

7.1 Measurements

The NIR spectra were measured also in the KCL laboratory from the hand sheets made for the analysis discussed in the chapter 6.2 using a laboratory IR-spectrum analysis device. Measurements were done from the samples 1–20 during August 2000 and from the samples 41–50 during December 2000. The first measurement set was used as the tuning set and the second as the test set.

Figure 12 shows the NIR spectra measured in the laboratory from the hand sheets. It can be observed that the online measured values of the TQA spectra have higher variation than the laboratory NIR spectra. The major reason to this is the large variation of the refined pulp consistency in the blow line compared to the much more stable moisture of the hand sheets.

There is only a slight variation inside the two individual sample sets, but excessive variation exists between the two separate sets. This must be related to some changes in the measurement conditions in the laboratory. The probable reason is a change in the sheet moisture, altered by handling of the sheets, or ambient humidity in the laboratory.

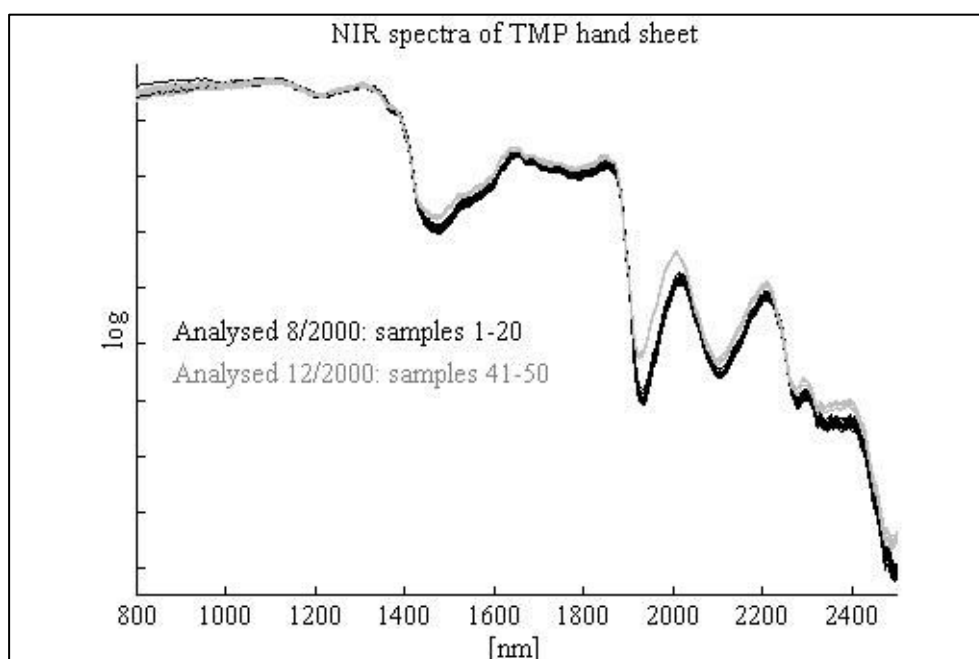


Figure 12. The NIR spectra measured in KCL laboratory from the hand sheets. Laboratory measurements were done in two periods, which are shown with black and grey color.

Figure 13 shows the ratio between the two measurement sets of the laboratory NIR spectra. This is closely similar with the Lambert absorption coefficient of water

(Kuusela, 1990). It concludes that the difference between the two measurement sets is related to the sheet moisture, and in practice tells nothing about the pulp quality.

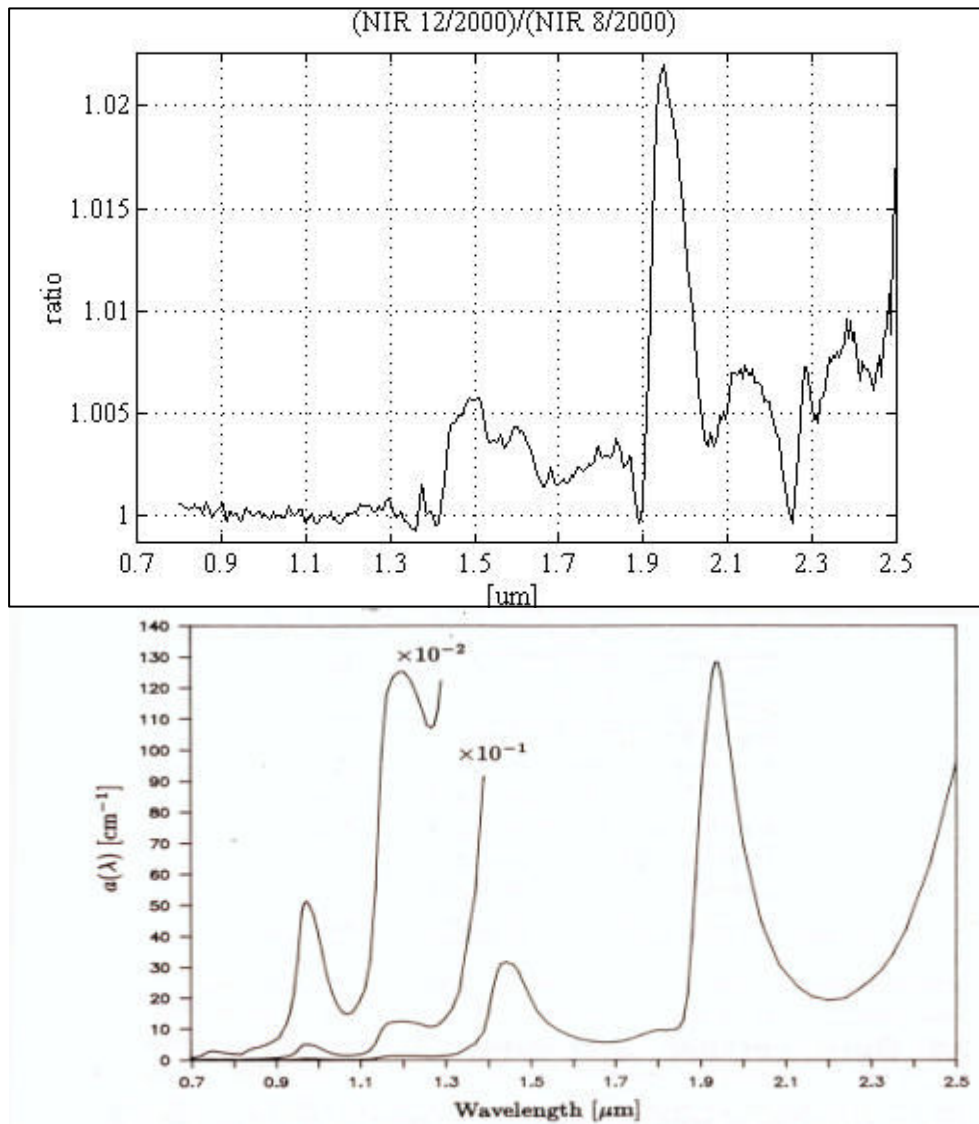


Figure13. The upper graph shows the average ratio between the two NIR-measurement sets of the hand sheets. The lower graph shows the Lambert absorption coefficient of water for corresponding wavelengths.

Naturally, the test result is poor due to this change in the measurement conditions. In order to improve this, the test set was scaled with the average ratio shown in the previous figure. It is not an adequate method, and the NIR spectra measurements in the laboratory should be done more carefully to keep the conditions stable. Therefore, these results should be considered as indicative, only.

7.2 Correlation with the pulp properties

The NIR spectra show the best correlation with the pulp properties, which are related to the bonding ability and fines content. The corresponding measurements were the

fibril content, sheet tensile index and light scattering. The lowest correlation was found for the fibre length and tear index.

Table 2 shows the test results based on the PLS-model. Bauer McNett analyses were done from the first 20 samples, only. The NIR spectra from the hand sheets were measured during one day so the measurements conditions were stable enough (Figure 12). Because of the small number of the samples, the results include some variations.

Samples 1–10 was used as the tuning set and samples-11–20 as the test set. The correlation was the best for the fine content of Bauer McNett fractions. The second best correlation was found for the light scattering. When the sheet strength is considered the tensile index shows a better correlation than the tear index.

Naturally, test results of the TQA measurement show the best correlation for the blow line consistency. The correlation of the tensile index and fibril content was also significantly better compared to the test results of the laboratory NIR spectra. The other properties are more related to the fibre dimensions and gave a weaker correlation.

The conclusion is that the NIR spectra measured online from the blow line may give significantly different results compared to NIR spectra measured from the hand sheets. In this case, TQA gave a better correlation for the pulp properties related to the bonding ability. The reason is caused by different measurement conditions.

Table 2. The test set correlation of the PLS modelling of the pulp properties with both the TQA and laboratory NIR spectra. The first 10 samples were used for tuning and the samples 11-20 for the test set.

	NIR-laboratory	TQA
Blow line consistency	0.44	0.96
Fiber length	0.52	0.05
Tensile index	0.33	0.92
Tear index	0.2	-0.04
Light scattering	0.62	0.58
BMcNett16	0.61	0.08
BMcNett200	0.31	0.02
Bauer McNett <200	0.82	0.54
Fibril content of Bauer McNett <200	0.49	0.72

7.3 Final testing

Figure 14 shows PLS model tunings with samples 1–20 and tests with samples 41–49 for the laboratory NIR spectra. The test set measurements were scaled with the ratio shown in the figure 14 to compensate for the differences between the spectra of the two sets. It means that this was not a real prediction test because average spectra of the test set had to be used in scaling.

As a result, the average error of the test set was small. However, the prediction efficiency was weaker, as the figure shows. The prediction of the fibre length was somewhat better and the prediction of the tensile index was weaker compared to the TQA measurements.

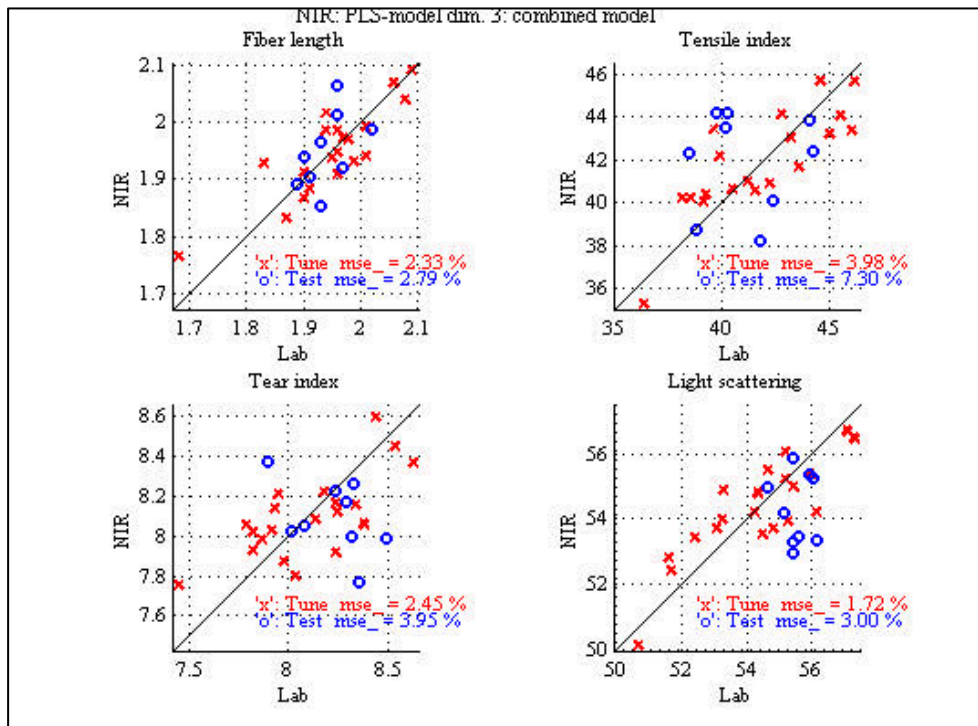


Figure14. PLS models of the pulp properties based on NIR spectra measurements of the hand sheets analysed in the KCL laboratory.

8 CONCLUSION

This research studied the applicability of the NIR-spectral analysis to measure different properties from the thermomechanical pulp. The measurements were done using an in-line TQA-analyzer installed directly in a blow-line of an industrial refiner line in Finland. The laboratory analyses of the collected samples were done in the Mechanical Process Engineering Laboratory, in University of Oulu.

The measurements proved that it is possible to measure the consistency, freeness and tensile index from the pulp. The measurements of the tear index and light scattering didn't give as good results due to the fact that it was not possible to get large enough variations in these variables for the calibration and testing. The achieved variations of the tear index and light scattering coefficient were just in the range of the accuracy of the laboratory analysis. Further studies are required with these variables, but based on earlier experiences especially the light scattering coefficient is expected to be possible to measure when the process conditions can be arranged suitable for the calibration and testing.

When measurement and laboratory accuracy's are compared, one fact affecting the results is the accuracy of the laboratory analysis itself, and especially the sampling. It is emphasised when blow line sampling is concerned. Therefore, careful sampling is underlined.

The hand sheets made for the laboratory analysis were also analysed in the KCL Laboratory using a laboratory NIR-analyser. These measurements gave the best correlation to the Bauer McNett <200 class and light scattering. When comparing the laboratory NIR and TQA measurements TQA gave better results with blow line consistency, tensile index, and fibril content. At least when the consistency is considered the reason is the different measurement conditions.

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