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IDENTIFICATION OF SEMICHEMICAL FLUTING PROPERTIES BY APPLICATION OF NEAR INFRARED SPECTROSCOPY

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ABSTRACT

Near infrared spectroscopy offers monitoring of raw materials and paper properties. The data from near infrared spectroskopy (NIR) spectra can by scanned directly on the surface of the handsheets and commercial paper. Data of NIR spectra of semichemical fluting correlate with the filler content, Kappa number as well as directly with strength properties. Concora medium test (CMT), short span compression test (SCT) and burst strength of semichemical fluting may be controlled by semichemical pulp and recovered fibers content in the furnish. Increasing filler content by 1 % results in decrease of CMT and SCT by 6.9-7.4 %, and burst strength by 12 %. Decreasing of strength may be compensated with increased semichemical pulp content in the furnish by around 9.5 %.

KEYWORDS: Effective residual ink concentration, fillers, Kappa number, NIR spectroscopy, pigments, recovered fibres, semichemical fluting, semichemical pulp, strength properties.

INTRODUCTION

The advantage of packing materials manufactured from corrugated board as a suitable protecting material lies in its high strength. The high interest in strength properties directly at paper manufacturers of case materials is therefore justified. Increasing trend to reduce basic weight of papers requires from manufacturers improvement of paper strength. Case materials represent wide scale of products such as liners, especially kraft liner, white kraft liner, test liner and flutings as semichemical fluting, recycled fluting, light weight recycled fluting and others, which vary in their final use. Recovered paper utilization in case material production in CEPI countries was in 2009 as high as 93 % (CEPI Annual statistic 2009). Recovered paper furnish composition of case materials manufactured in 2009 in Europe consisted mainly of recovered fibres (74 % corrugated and kraft, 21 % mixed grades, 4.5 % news, magazines and high grades) and only of 0.5 % virgin fibres. Test liner and recycled fluting contains 100 % recovered fibres. Gradual increase of mineral fillers, coating pigments and very tiny fibre fragments (crills) are expected in paper and board.

Mineral fillers and pigments are lowering bonding ability in the paper sheet reducing especially flexural rigidity of paper. Crill increases bonding in the paper sheet. The content of mineral fillers and pigments in the recovered fibres can be reduced or nearly eliminated by flotation and washing.

SCT is only slightly positively influenced by flotation and washing of recovered fibres. During extreme washing, connected with losses of fines, the trend is inverted; SCT may fall below the initial level. CMT is hardly influenced by flotation and washing (Selder et al. 2002).

Currently quality control of corrugated board production is based on laboratory measurements of the interoperation control. Semichemical fluting consists of varying proportions of semichemical pulp and recovered fibers. Semichemical pulp as compared to recovered fibers has higher lignin content, but is free of mineral fillers, pigments and printing inks. Recovered fibres contain mineral fillers, pigments and printing inks. Strength potential of semichemical fluting may be based on controlled furnish composition consisting of semichemical pulp and recovered fibres (Gigac et al. 2008). Beating of semichemical pulp significantly improves strength properties. Beating of recovered fibres is advantageously applied on fractions of long recovered fibres during production of high quality test liners (Ortner et al. 2006).

The forming unit of the paper machine plays the key role in production of high grade papers. Large open surface and depth of open structure of the forming roll of twin wire forming unit have a positive influence on typical strength properties such as SCT and burst strength of test liner (Müller and Turpeinen 2007). A suitable difference of jet-to-wire speed generates a z-directional velocity gradient shear field that creates turbulence, which breaks the flocks enabling good distribution of mass in surface of paper, fibre orientation, anisotropy, curling and strength properties of paper (Banecki 2004, Gigac and Fišerová 2010a). The first information about strength properties is known only after sample collection on the end of the process of turn-up (the first case uses laboratory measurements of samples taken from a reel after turn-up), and so the changes of process parameters aimed to regulate strength properties in real time are not possible.

Several publications are focused on prediction of physical and mechanical properties of paper and of paper machine parameters control by means of using adaptive technologies in process modeling applying neuron networks in management and controlling (Schweiger and Rudd 1994, Ferguson 2007). In recent years, new on-line measurements have been developed in order to characterize qualitative characteristics such as porosity (Paavola and Machattie 2008), formation, fibre orientation (Chapman et al. 2001), strength properties (Ridgway et al. 2004) and contact-free thickness measurements, which don't require samples taking from the end of the paper reel. In order to obtain continuous record and control of flexural rigidity while increasing recovered fibres content in the furnish, a non-destructive method was applied in the Austrian Mayer-Melnhof Karton paper mill (Garnett 2008, Hui et al. 2008).

Soft extensional stiffness sensor (ESS) sensor measuring strength properties with similar techniques as a laboratory testing instrument is constructed so that it can withstand rough manipulation and has the dynamics of machine equipment. On-line measurements proved effective and strong relationship with laboratory tests including ring crush test (RCT), SCT, flexural rigidity and anisotropy of strength properties. It is expected that applying NIR spectroscopy equipped with fast sensors offers possibilities for on-line measurements of paper properties. Development of exact and stable NIR-callibration algorithms makes it possible to apply this process for determination of paper characteristic parameters (Furumoto et al. 1999, Hartenstein et al. 2002, Pensold and Plew 2003, Trafela et al. 2007, Gigac and Fišerová 2010b). Several years ago research results dealing with on-line version of NIR spectroscopic device were published; conditions suitable for measurement and prediction of paper web strength properties of fluting and test liners were studied (Behnsen

2008). Besides measurements and predictions of strength properties it is also necessary to solve aspects and elements of systems for coordination between paper machine wet and dry part from process coordination point of view (Lang et al. 2001).

Quality control by destructive analyses of paper samples collected from the end of each or each i^{th} reel on the paper machine does not offer immediate information during production and makes not possible adequate intervention which could be carried out accordingly.

The objective of this work is find out correlation between optical and strength properties of commercial semichemical fluting by NIR spectroscopy.

MATERIAL AND METHODS

Material

Samples of 45 commercial papers:

- semichemical fluting, type SC - basic weight ranging from 112 to 180 $g.m^{-2}$, Kappa number from 113 to 125, semichemical pulp content 55-75 %, ash content: 4.4 % to 7.2 %, effective residual ink concentration (ERIC 950) from 397 ppm to 854 ppm.
- semichemical fluting, type EX – basic weight ranging from 150 to 165 $g.m^{-2}$, Kappa number 135, semichemical pulp content 80-85 %, ash content from 3.4 % to 3.8 %, ERIC 950 from 347 ppm to 395 ppm.

Samples of both types were produced on a paper machine with single wire forming unit at a paper machine speed of 350-550 $m.min^{-1}$ depending on basic weight and at constant jet flow and wire speed difference (draw). The adjusted speed difference of the jet-to-wire (draw -18±0.5 $m.min^{-1}$) corresponded to an area suitable for paper production of maximum CMT.

Methods

Destructive methods were used for determination of the following paper properties: basis weight (ISO 536/1995), crushing stiffness SCT according short span compression test (ISO 9895/1989), effective residual ink concentration ERIC 950 by measurements in the infrared area of the spectrum at the wavelength 950 nm based on provisional method T 567 pm-97 (Vahey et al. 2006), fillers/coating pigments content as residue ash on ignition at 525°C (ISO 1762), flat crush resistance of a sample fluted in laboratory according the Concora Medium Test (ISO 7263/1994), burst strength according to ISO 287 and Kappa number according to ISO 302 standard.

For no contact, non-destructive measurement of paper properties, the FTIR/NIR spectrometer Nicolet iS 10 was used with methodology of diffused DRIFT. Diffusion-reflectance component of the reflection during sample analysis carries information about absorption properties of the studied sample. The NIR spectral data was collected using the Omnic version 8.0 software by Thermo Scientific. The experiment setup was the following: Number of scans: 3 x 128; resolution: 4; data spacing 0.482 cm^{-1}; range of wave numbers 4200-5940 cm^{-1}. The collected spectra were analyzed and evaluated using the TQ Analyst version 8.0 software by Thermo Scientific.

RESULTS AND DISCUSSION

Relationships between the predicted and measured laboratory values of CMT_{30}, short span compresion test machin direction (SCT_{MD}), SCT_{CD}, burst strength, filler content, Kappa number and effective residual ink concentration ERIC 950 are shown on Figs.

1-7. Proportionality of predicted and measured properties expressed with direction of the line descended in this order: filler content 0.90, CMT_{30} 0.91, SCT_{MD} 0.86, Kappa number 0.96, SCT_{CD} 0.68, burst strength 0.69 and effective residual ink concentration ERIC 950 0.48. Relative deviation of the line shift with respect to 0 on the Y axis (y=p.x+q) rose with respect to the average value in the following order: Kappa number 3.5 %, CMT_{30} 8 %, filler content 10 %, SCT_{MD} 13 %, burst strength 25 %, SCT_{CD} 30 % and the effective ink concentration ERIC 950 up to 42 %. Each figure description contains the used partial least squares (PLS) factor and error of root mean square error of calibration (RMSEC).

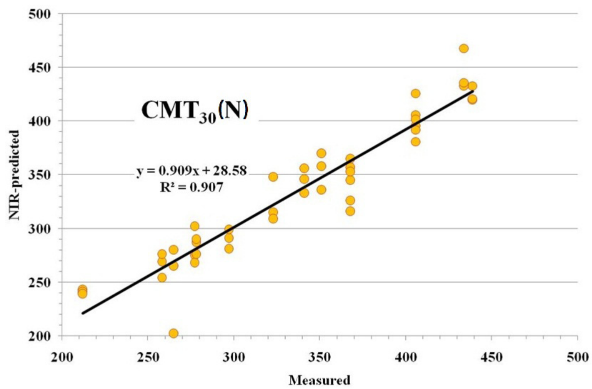

Fig.1: Comparison between predicted and measured values of semichemical fluting CMT_{30} (Factor used 5, RMSEC 16.4)

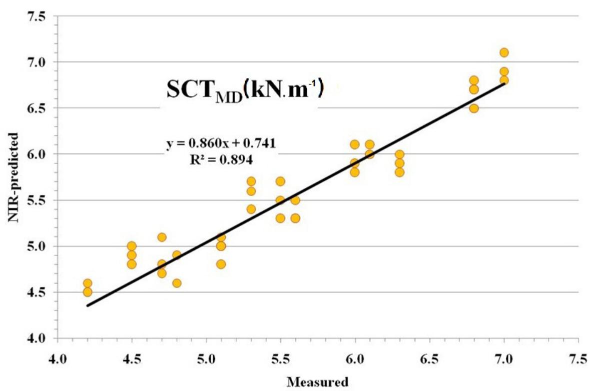

Fig. 2: Comparison between predicted and measured values of semichemical fluting SCT in machine direction (Factor used 4, RMSEC 0.211)

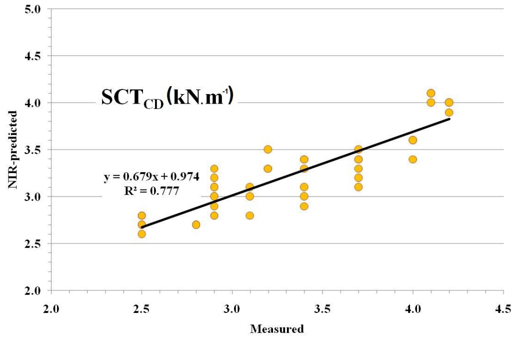

Fig. 3: Comparison between predicted and measured values of semichemical fluting SCT in cross direction (Factor used 1, RMSEC 0.322)

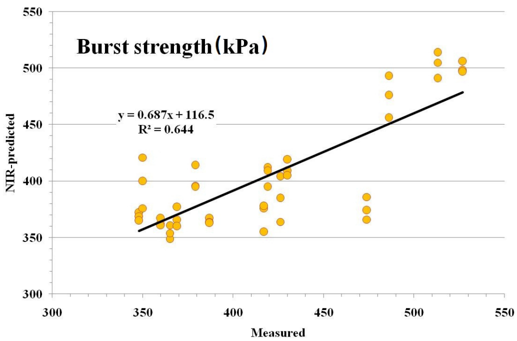

Fig. 4: Comparison between predicted and measured values of semichemical fluting burst strength (Factor used 3, RMSEC 76.4)

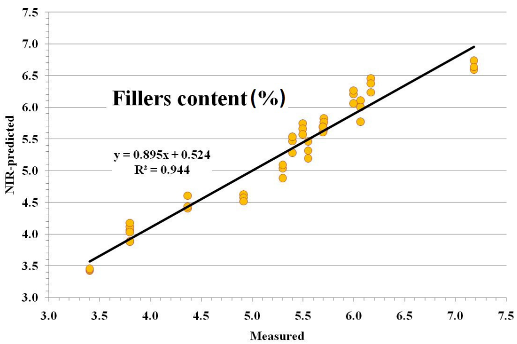

Fig. 5: Comparison between predicted and measured values of fillers content in semichemical fluting (Factor used 2, RMSEC 0.203)

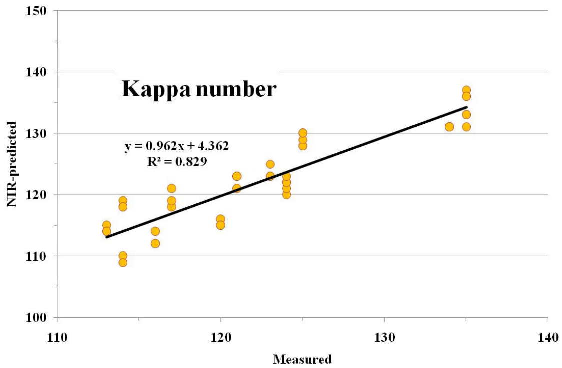

Fig. 6: Comparison between predicted and measured values of semichemical fluting Kappa number (Factor used 2, RMSEC 2.39)

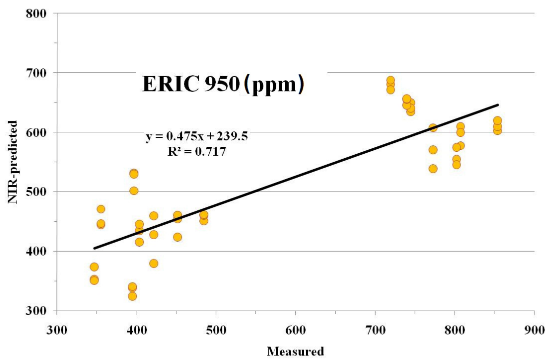

Fig. 7: Comparison between predicted and measured values of semichemical fluting effective residual ink concentration ERIC 950 (Factor used 1, RMSEC 84.2)

Proximity of relationships, which was obtained between each individual predicted and measured paper properties, or variability of values, is compared in Fig. 8 with the aid of correlation coefficients. Correlation coefficient was decreasing in order from concentration of filler content at 0.97, CMT_{30} and SCT_{MD} 0.95, Kappa number 0.91, SCT_{CD} 0.88, effective residual ink concentration ERIC 950 0.85 and burst strength 0.80. Between NIR-predicted and measured effective residual ink concentration ERIC 950 (Fig. 7), low proportionality 0.48 was achieved, relatively high deviation of shift of as much as 42 % and determination coefficient R^2=0.717. Except for low parameters, relationship discussed in Fig. 7 was constructed practically from two clusters of predicted and measured ERIC 950 values.

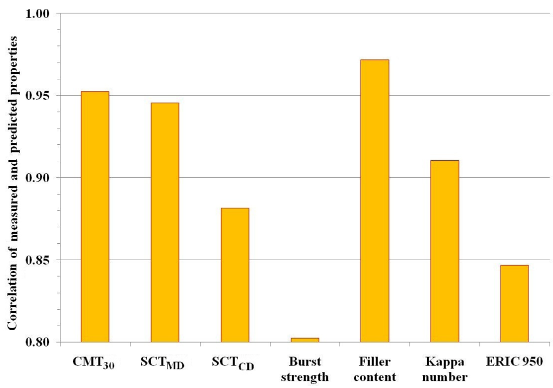

Fig. 8: Correlation coefficients of relationships between predicted and measured paper properties

We have evaluated relationship between predicted paper strength properties and predicted filler content, Kappa number and effective residual ink concentration ERIC 950. Predicted strength properties in relation to the predicted filler content are shown in Figs. 9-12 and relation with Kappa number in Figs. 13-16. Strength properties in Figs. 9-16 are recalculated to a basic weight of 127 $g.m^{-2}$.

Value changes of filler content and Kappa number, which result from equations shown in Figs. 9-16 are the following in the given order. Increasing filler content by 1 % decreased CMT by 25.7 N, SCT_{MD} by 0.41 $kN.m^{-1}$, SCT_{CD} by 0.26 $kN.m^{-1}$ and burst strength by 43.2 kPa. Relative decrease in strength was the highest for burst strength at 12 % and 6.9-7.4 % decrease was recorded for others. Increasing Kappa number by 10 units has increased CMT by 31.6 N, SCT_{MD} by 0.50 $kN.m^{-1}$, SCT_{CD} by 0.31 $kN.m^{-1}$ and burst strength by 51.9 kPa. Relative rise in strength properties was the highest for burst strength at 14.4 %, and 8.4-9.0 % for others. Decrease of strength properties resulting from increasing the filler content by 1 % is possible to compensate by increasing Kappa number by 8.1-8.3 units, which corresponds to increase of furnish of semichemical pulp by 9.3 %.

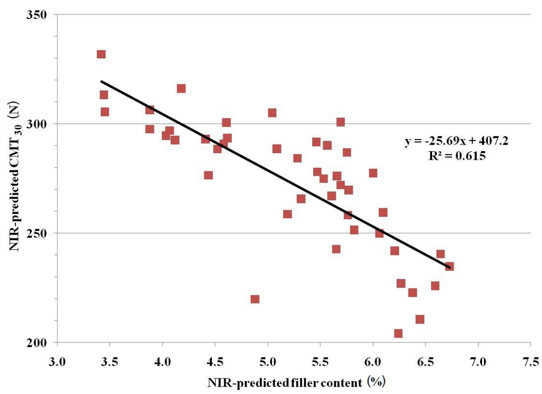

Fig. 9: Influence of filler content on CMT_{30} of semichemical fluting

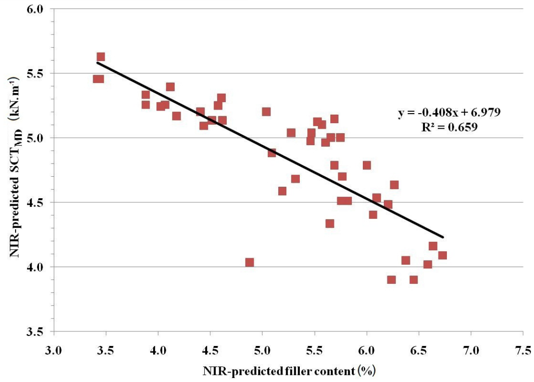

Fig. 10: Influence of filler content on SCT of semichemical fluting in machine direction

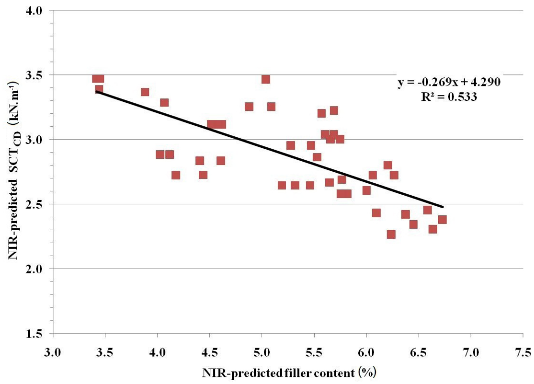

Fig. 11: Influence of filler content on SCT of semichemical fluting in cross direction

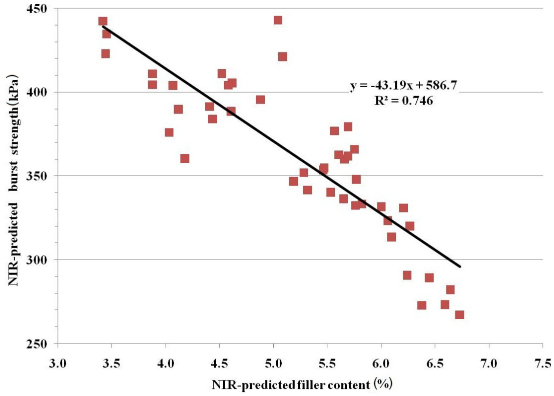

Fig. 12: Influence of filler content on burst strength of semichemical fluting

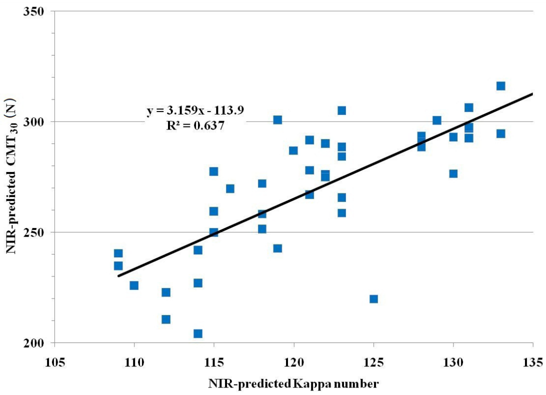

Fig. 13: Influence of Kappa number on CMT_{30} semichemical fluting

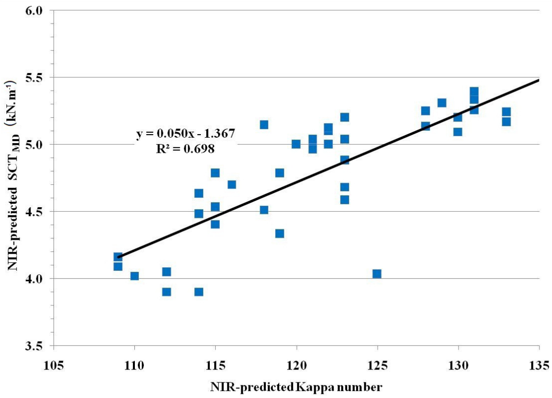

Fig. 14: Influence of Kappa number on SCT of semichemical fluting in machine direction

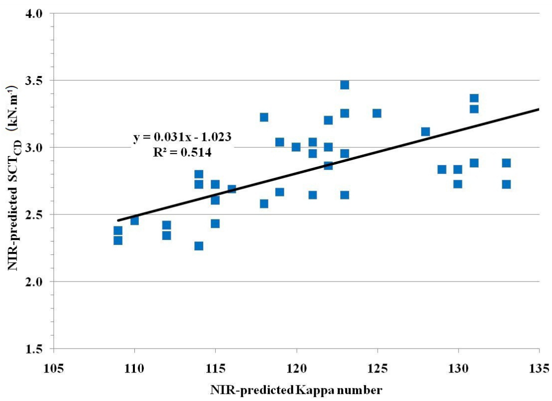

Fig. 15: Influence of Kappa number on SCT of semichemical fluting in cross direction

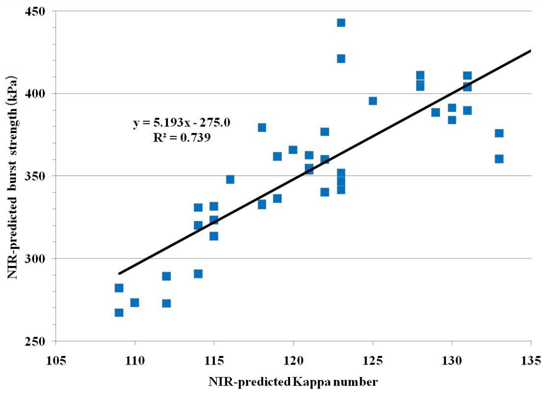

Fig. 16: Influence of Kappa number on burst strength of semichemical fluting

Correlations of predicted values of CMT_{30}, SCT_{MD}, SCT_{CD} and burst strength with predicted values of filler content and Kappa number in paper is shown in Fig. 17. The best correlation was reached for relationships burst strength versus filler content (R_F 0.83) and burst strength versus Kappa number (R_K 0.84). The correlation coefficients another strength properties decreased in the following order: SCT_{MD} (R_F 0.81 and R_K 0.84), CMT_{30} (R_F 0.78 and R_K 0.78) a SCT_{CD} (R_F 0.73 and R_K 0.72).

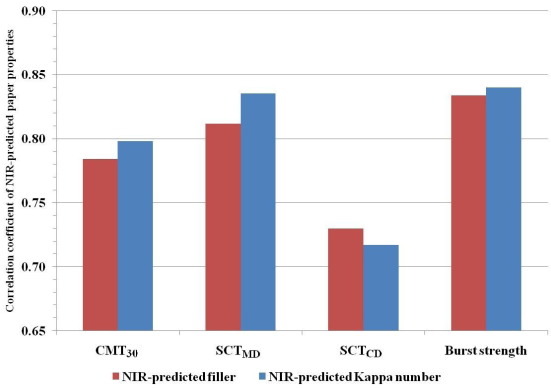

Fig. 17: Correlation between CMT_{30}, SCT in machine and cross direction and burst strength, filler content and Kappa number of semichemical fluting

Very low values of correlation coefficient were witnessed for the relationship between effective residual ink concentration ERIC 950 and paper strength properties (Tab. 1). It is in contradiction with the results obtained in our previous work (Gigac and Fišerová 2010b) during modeling of handsheets. The reasons may arise from uneven quality of waste paper, uneven conditions at recovered fibres production and uneven print ink retention on wet end of paper machine. During laboratory modeling, waste paper of even quality has been used as far as the content of print ink. Also, constant conditions sustained during of recovered fibres and handsheets preparations.

Tab. 1: Correlation between semichemical fluting strength properties and effective residual ink concentration ERIC 950 determined by NIR spectroscopy (expressed as correlation coefficient)

Properties	ERIC 950 (ppm)
CMT_{30}	0.34
SCT_{MD}	0.30
SCT_{CD}	0.43
Burst strength	0.41

CONCLUSIONS

Analysis of 45 samples of two grades of commercial semichemical fluting of semichemical pulp content between 55 and 85 %, filler content between 3.4 and 7.2 % and effective residual ink concentration ERIC 950 between 347 and 854 ppm led to the following results:

1. Correlation analysis provides information about the use of NIR spectra for determination of paper strength properties, of mineral fillers and pigments content and semichemical pulp content in semichemical fluting.
2. Information from the NIR spectra of semichemical fluting correlate very well with filler content (R 0.97), Kappa number (R 0.91) and strength properties CMT_{30} and SCT_{MD} (R 0.95), SCT_{CD} (R 0.88) and burst strength (R 0.80).
3. Correlation between predicted strength properties and filler content decreased in the following order: burst strength (R 0.83), SCT_{MD} (R 0.81), CMT_{30} (R 0.78) and SCT_{CD} (R 0.73).
4. Correlation between predicted strength properties and Kappa number decreased in the following order: burst strength and SCT_{MD} (R 0.84), CMT_{30} (R 0.78) and SCT_{CD} (R 0.72).
5. Correlation between predicted strength properties and effective residual ink concentration ERIC 950 reached very low values (R 0.30-0.43). The reason for low correlation may be unevenness of waste paper quality, lack of constant production conditions in processing of waste paper into recovered fibers and during dewatering of the wet web on the paper machine.
6. Increasing filler content by 1 % decreased CMT_{30} by 25.7 N, SCT_{MD} by 0.41 $kN.m^{-1}$, SCT_{CD} by 0.26 $kN.m^{-1}$ and burst strength by 43.2 kPa.
7. Increasing Kappa number by 10 units increased CMT_{30} by 31.6 N, SCT_{MD} by 0.50 $kN.m^{-1}$, SCT_{CD} by 0.31 $kN.m^{-1}$ and burst strength by 51.9 kPa.
8. Decrease of strength properties due to increase of filler content by 1 % may be compensated by increasing semichemical pulp content in the furnish by 9.5 %.

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