EFFECT OF VELOCITY GRADIENT ON PAPERMAKING PROPERTIES

JURAJ GIGAC and MÁRIA FIŠEROVÁ

Pulp and Paper Research Institute, Lamačská cesta 3, 841 04 Bratislava, Slovak Republic

Received December 17, 2009

The influence of velocity gradient on the anisotropy of tensile stiffness index, tensile energy absorbance, tensile index, tear strength, tensile stiffness orientation, formation and curl of MG paper, as well as on the anisotropy of coating raw paper, was investigated. The maximum strength of MG paper was achieved in the 0.93-1.05 range of the jet-to-wire speed ratio. The best formation and the lowest curl with fibre orientation ±1.7° was achieved at a jet-to-wire speed ratio around 1.0, while CMT and SCT of fluting from a mixture of semi-chemical pulp and recovered fibres produced at a constant speed difference of the jet and wire are influenced by basis weight and semi-chemical pulp content.

Keywords: anisotropy, coating raw paper, correlation analysis, curl, fibre orientation, fluting, formation, MG paper, paper machine, process control, strength properties

INTRODUCTION

Paper properties, which are mainly the result of fibre strength and fibre bonding properties, are significantly influenced by pulp refining and by the operating conditions of the wet end and drying part of the paper machine. An optimisation of the operating conditions is necessary to produce paper with required properties and to increase productivity. Low headbox consistency and turbulence preventing flocculation is a prerequisite for good formation, over a normal range of fibre concentrations.[1] On Fourdrinier machines, the possibilities to improve formation are limited, while much higher formation improvements are possible on hybrid and gap formers.[2,3]

A suitable difference of the jet-to-wire speed generates a z-directional velocity gradient shear field that creates turbulence, which breaks the flocks. The shear field rotates the fibres in machine direction. Consequently, at a great speed difference, the fibres are more oriented in machine direction.[4] Fibre orientation directly affects the in-plane mechanical properties and dimensional stability of paper.

The anisotropy of paper properties also depends on the wet straining of the drying shrinkage and of the paper web. The anisotropy of the paper properties is the result of fibre orientation and of other factors as well, but their weight is not known exactly.

The influence of formation on the physical properties of paper, especially on tensile strength and tearing resistance, was studied versus fibre fractionation.[5] A high difference between jet and wire speed is favourable for burst strength and formation, but it has a negative influence on SCT in cross direction and on the ply bond of papers and boards.[6]

The control of paper machine parameters related to paper quality involves two aspects: indirect control and model-based control.[7] Indirect control is based on laboratory measurements of samples taken from a reel. Performing indirect control or statistical modelling techniques, or both, represents a progressive concept. Many continuous processes, however, exhibit characteristics that make these modelling and control techniques difficult.[7,8]

The objective of this work was to compare the influence of velocity gradient, on paper machines of 220 to 550 m/min speed, on the formation, anisotropy and strength properties of MG paper, coating raw paper and fluting, for collecting data for a control model of paper strength properties.

EXPERIMENTAL

Materials

Samples of commercial papers were used: 33 g/m^2 MG paper, 48 g/m^2 coating raw paper (from bleached kraft hardwood and softwood pulp furnish) and 112-175 g/m^2 fluting (from a furnish of 57-78% unbleached semi-chemical hardwood pulp and 22-43% recovered fibres). The sampling places of MG paper and coating raw paper were marked on the reel at short intervals of 7 to10 min, after changing the air cushion pressure in the headbox. The paper machine speed at MG paper production was of 220 m/min and, at coating base paper – of 410 m/min. The samples from the marked places were collected from the reel on the rewinder. Fluting samples were collected during production at a constant difference of paper stock and wire speed. Paper machine speed in the 350-550 m/min range was adjusted to required paper basis weight. Fluting was sampled during one month, from the end of 277 reels.

Methods

The formation of papers was evaluated on a Toyo Seiki Formation Tester or Ambertec Beta Formation Tester, and also by the subjective method based on pair comparison of samples, expressed as a PC index.[9] A higher value of the pair comparison index (PCI) corresponds to better formation. The tensile stiffness index (TSI) and tensile stiffness orientation (TSO) were measured by the Loretzen & Wettre ultrasound tester. Tensile energy absorbance (TEA) and tensile index (TI) were determined according to ISO 1924/2 method, using an Instron 1011 tester. Tearing resistance (TR) was measured according to ISO 1974 method. The curl problem is an interaction of furnish composition, paper formation, conditions of drying and surface treatment. The value of curl (K), which is a quantitative measure of paper sample deviation from an even surface, was expressed as the reversed value of the curvature diameter 1/R, in m^{-1}. For evaluating the coating raw paper curling, the so-called Warm-oven curl test[10] was applied. Oven air temperature was of 95 °C and heating time – of 90 s. The short span compression test (SCT) of fluting was measured according to ISO 9895 standard and the Concora medium test (CMT) – according to ISO 7263.

RESULTS AND DISCUSSION

In the first part of this work, the influence of velocity gradient on the properties of an MG 33 g/m^2 basis weight paper, produced on a Fourdrinier Yankee type paper machine, at 220 m/min speed, was investigated. Figure 1 shows the influence of velocity gradient, expressed as jet-to-wire speed ratio, on the anisotropy of tensile stiffness index, tensile energy absorbance, tensile index and tearing resistance of paper. All curves attain a minimum in the region close to the 1.0 jet-to-wire ratio. A jet-to-wire speed ratio under or over 1.0 increases strength anisotropy. The anisotropy of strength properties, which is the ratio of strength properties in wire movement direction to cross direction, is also influenced, besides the velocity gradient, by the tension of the paper sheet during drying. This is explained by the generation of a velocity gradient, resulting in a better orientation of the fibres in wire movement direction. The decrease of strength anisotropy at a jet-to-wire speed ratio under 0.9 and over 1.5 is explained by the significant deterioration of paper formation. The highest TEA anisotropy was observed at a jet-to-wire speed ratio of 1.14, most probably caused by the combination of fibre orientation and rush of paper stock on the wire. Under such circumstances, the paper web is less stretched. A similar effect is caused by reduced straining between the press section and the drying part, between the drying sections or by the micro crepe bag paper formation.

Figure 2 shows the dependence of tensile energy absorption on the jet-to-wire speed ratio. Tensile energy absorption curves in machine direction, of average value, have a significant minimum at a jet-to-wire speed ratio 1.0. Both curves have a convex shape and a less pronounced course than the anisotropy curves of strength properties shown in Figure 1. The strength properties of paper in cross direction follow a concave curve with a maximum in the 0.93-1.05 range of the speed ratio. The optimum jet-to-wire speed ratio can be adjusted according to strength requirements in machine and cross direction. To achieve high strength in both directions, the speed ratio should be adjusted to the level of 0.93 or 1.05.

Figure 3 shows the dependence of formation on the jet-to-wire speed ratio at two stock concentrations. At a lower concentration (3.3 g/L), corresponding to a larger headbox slice (15 mm), good paper formation was achieved over the entire jet-to-wire speed ratio range. The formation was measured with a Toyo Seiki instrument expressing the variability of paper basis weight. A higher percentage of variability means lower formation. The best paper formation was achieved at a jet-to-wire speed ratio around 1.0.

The second part of this investigation analyzes the influence of velocity gradient on the formation, tensile stiffness orientation and curl of coating raw paper (48 g/m^2) produced on a Fourdrinier paper machine at a 410 m/min speed. Figures 4A and 4B show the influence of velocity gradient, expressed by difference, of jet and wire speed on the formation of coating raw paper at a speed difference from -35 m/min (drag) to +25 m/min (rush). Figure 4A shows formation evaluated as percentage of paper basis weight variability, measured with an Ambertec Beta Formation tester. The best formation was achieved at a drag value of -3 m/min. An identical result was achieved by the perceptual method of pair comparison index, as shown in Figure 4B.

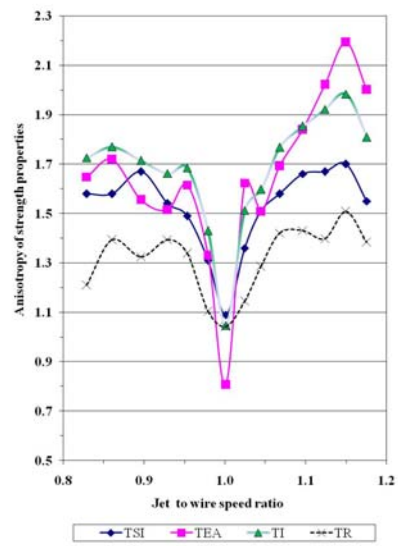

Figure 1: Influence of jet-to-wire speed ratio on the anisotropy of tensile stiffness index, tensile energy absorbance, tensile index and tear strength of MG paper

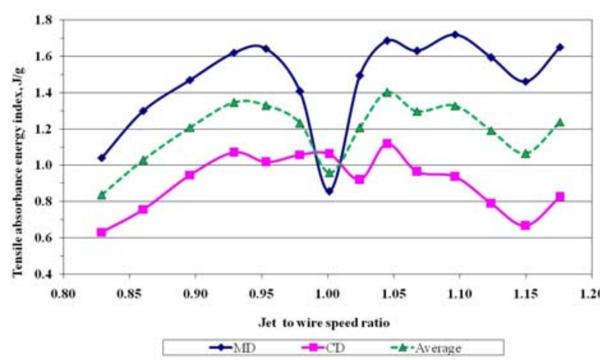

Figure 2: Influence of jet-to-wire speed ratio on tensile energy absorbance of MG paper in machine direction, cross direction and on average value

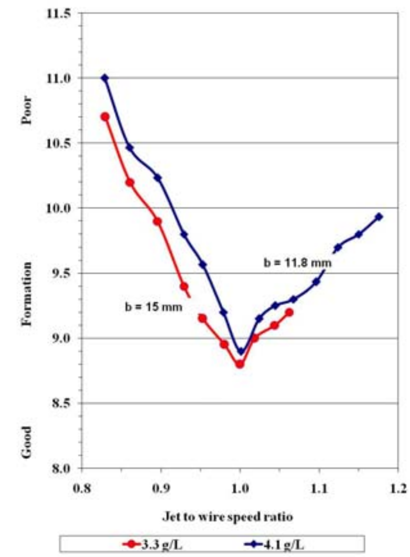

Figure 3: Dependence of MG paper formation on jet-to-wire speed ratio (Toyo Seiki Formation Tester)

Figure 5 shows the influence of jet and wire speed difference on tensile stiffness orientation (TSO) and curl of coating raw paper. In many cases, TSO is considered to be connected with the orientation of fibres, which is valid only in some cases.[11] TSO was measured by an ultrasound method using a Lorentzen & Wettres instrument. In the range of jet and wire speed difference from drag -7 m/min to rush +3 m/min, shown as a grey region, TSO was between ± 1.7° and curl – from 2.0 to 2.5 m^{-1}. Beyond this range, the curl and TSO of paper were significantly worse. In the described range, a good flatness of the paper was achieved. The curl of paper produced outside this range increased to an unacceptable level of 3.0.

The last part of this investigation discusses the variability of the strength properties of fluting produced on a Fourdrinier paper machine, at a 350-550 m/min speed and constant speed difference of jet and wire. A constant speed difference of -18 m/min represents a jet-to-wire speed ratio of 0.95-0.97, depending on the paper machine speed, and adjusted to achieve maximum CMT values over the whole range of the applied speed. Figures 6 and 7 show the influence of basis weight on the strength properties of fluting. The coefficient of CMT determination *vs*. the basis weight relationship was R^2 = 0.872, for SCT in machine direction – R^2 = 0.743, and in cross direction – R^2 = 0.799.

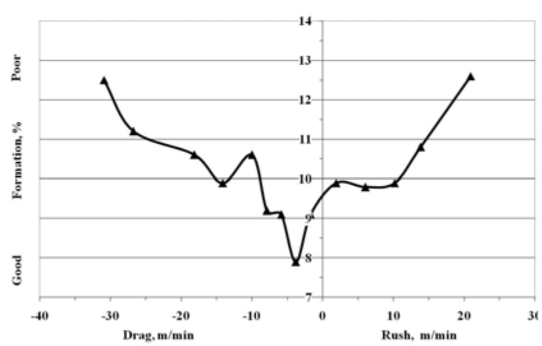

Figure 4A: Dependence of coating raw paper formation (Ambertec Beta Formation Tester) on jet and wire speed difference

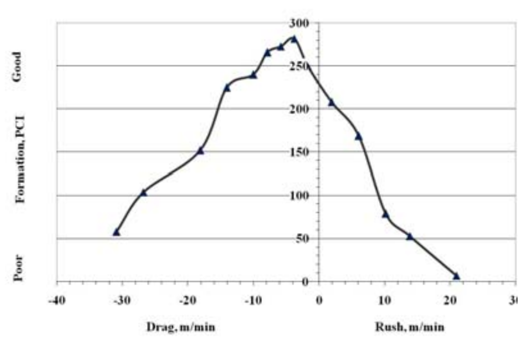

Figure 4B: Dependence of coating raw paper formation (pair comparison index) on jet and wire speed difference

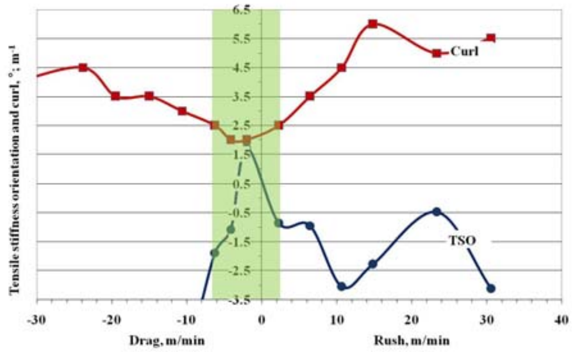

Figure 5: Dependence of tensile stiffness orientation (ultrasonic method) and curl of coating raw paper on jet and wire speed difference

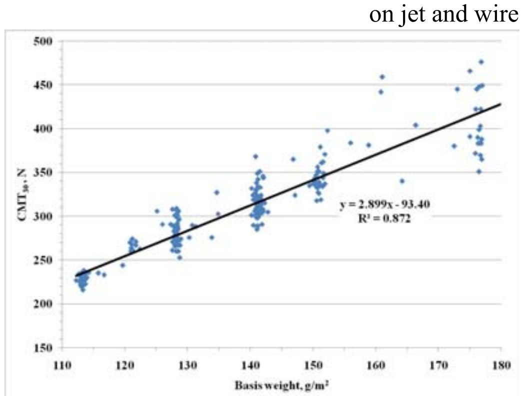

Figure 6: Influence of fluting basis weight on CMT

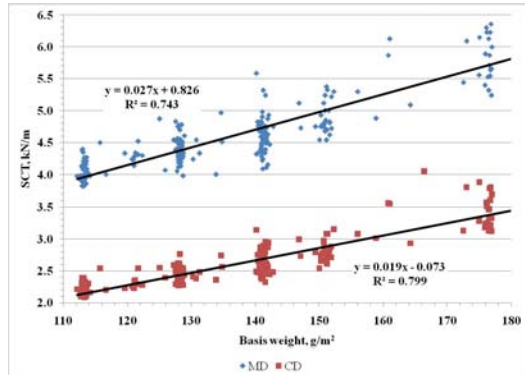

Figure 7: Influence of fluting basis weight on SCT in machine and cross direction

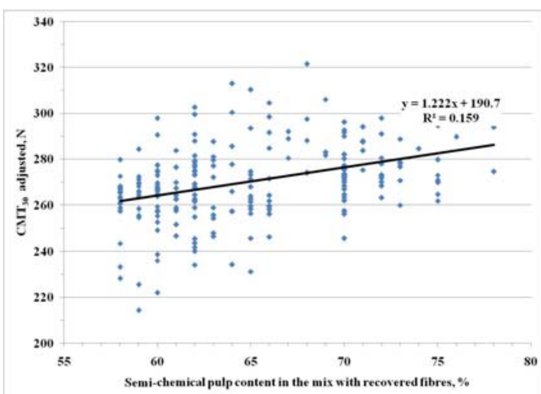

Figure 8: Influence of semi-chemical pulp content in mixture with recovered fibres on fluting CMT adjusted to 127 g/m^2 basis weight

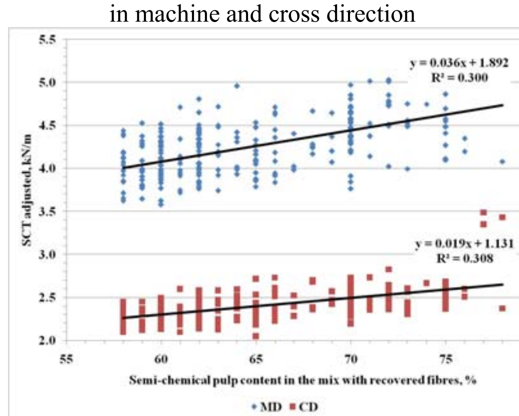

Figure 9: Influence of semi-chemical pulp content in mixture with recovered fibres on fluting SCT adjusted to 127 g/m^2 basis weight

Figures 8 and 9 plot the relationships between CMT and SCT fluting and the semi-chemical pulp content in a mixture with recovered fibres. The measured CMT and SCT data of fluting were recalculated for a basis weight of 127 g/m^2. This adjustment of the CMT and SCT values was based on the dependence of these properties on basis weight, determined experimentally. The correlation between adjusted fluting CMT values and semi-chemical pulp content (58-78%) in mixtures with recovered fibres is poor – R^2 = 0.159. The correlation of the fluting SCT values with the semi-chemical pulp content was slightly better; the determination coefficient, R^2, in machine direction was of 0.300, and in cross direction – R^2 = 0.308. Consequently, the semi-chemical pulp content explains the relation with CMT and SCT at a level of only 16-30%. The remaining 70-84% may be related to the inaccuracy in the determination of the semi-chemical pulp content in the mixture, to the variability of recovered fibre quality, related especially to filler and coating pigment content, to the uneven retention of fines on the paper machine wire, variability of the broken portion, semi-chemical pulp refining and hornbeam, poplar and birch content in the chip mixture used for semi-chemical pulp production. As known, the mineral particles content reduces CMT more than SCT. The correlation of CMT with the semi-chemical pulp content is significantly lower than the correlation of SCT, which can be explained by the high variability of the recovered fibres used in one-month evaluation.

CONCLUSIONS

The changes in the jet-to-wire speed ratio influenced the anisotropy of tensile stiffness index, tensile energy absorbance and tensile index, tear strength, tensile stiffness orientation, formation and curl of MG paper and the anisotropy of coating raw paper.

The adjustment of the jet-to-wire speed ratio permits to change the strength properties of paper. The maximum strength of MG paper in cross direction was achieved in the 0.93-1.05 range of the jet-to-wire speed ratio. To achieve a high strength in machine direction and in both directions, the jet-to-wire speed ratio should be of 0.93 or 1.05. A better formation was achieved at a lower stock concentration for the entire jet-to-wire speed ratio used in this investigation. The best formation was achieved at a jet-to-wire speed ratio of around 1.0.

In coating raw paper production over a range of jet-to-wire speed difference from -7 m/min to +3 m/min, good results were achieved, as follows: TSO of ± 1.7° and curl of paper – 2.0-2.5 m^{-1}. The lowest curl (2 m^{-1}) and the best formation (7.8%) were achieved at a drag of -3 m/min and at TSO of +1.7°. Out of this range, unacceptable curl and worsening of coating raw paper formation were observed.

The maximum CMT of fluting was achieved at a jet and wire speed difference of -18 m/min, corresponding to a jet-to-wire speed ratio of 0.95-0.97, as depending on the paper machine speed in the 350-550 m/min range. It was found out that, under these conditions, the coefficient of determination of CMT *vs*. the basis weight relationship was R^2 = 0.872, of SCT in machine direction – R^2 = 0.743, and in cross direction – R^2 = 0.799. The semi-chemical pulp content in the mixture with recovered fibres also influenced the CMT and SCT of fluting, but the coefficients of determination were low. The reasons for this were most probably the inaccurate determination of the semi-chemical pulp content in the mixture with recovered fibres, the variability of recovered fibre quality, uneven retention of fines on the papermaking wire, variability of broke content, as well as the quality and refining of semi-chemical pulp.

ACKNOWLEDGEMENTS: This work was supported by the Slovak Research and Development Agency under contract No. APVV-0340-07.

REFERENCES

[1] K. Knuts, K. Ebeling, J. E. Laine and M. Peura, *Pap. Puu*, **63**, 676 (1981).
[2] A. Kiviranta, *Procs. TAPPI Papermaker Conference*, TAPPI PRESS, Atlanta, 1996, p. 239.
[3] D. Egelhof and A. Bubik, *Wbl. f. Papierfabr.*, **122**, 111 (1994).
[4] K. Niskanen, in "Papermaking Science and Technology", Book 16, Paper Physics, Fapet Oy, Helsinki, 1998, p. 38.
[5] W. Karnchanapoo, A. Palokangas and M. M. Nazad, *Procs. 55th Appita Annual Conference*, Hobart, Australia, April 30-May 2, 2001.
[6] R. Banecki, *Wbl. f. Papierfabr.*, **132**, 101 (2004).
[7] K. J. Niskanen, in "Fundamentals of Papermaking", edited by C. F. Baker and V. W. Punton, Mech. Eng. Publ., London, 1989, Vol. 1, pp. 275-308.
[8] C. A. Schweiger and J. B. Rudd, *Tappi J.*, **77**, 201 (1994).
[9] J. Gigac and M. Fišerová, *Appita J.*, **62**, 208 (2009).
[10] C. Green and J. Atkins, *Solutions*, **01**, 40 (2001).
[11] T. R. Hess and P. H. Brodeur, *J. Pulp Pap. Sci.*, **22**, J160 (1996).