PAPER PHYSICS
Nordic Pulp & Paper Research Journal Vol 33 No 00 2018 — DOI

Effect of softwood kraft fiber coarseness on formation and strength efficiency in twin-wire roll forming

Bengt Nordström and Lennart Hermansson

KEYWORDS: Kraft pulps, Fiber coarseness, Fiber length, Twin wire machines, Jet to wire speed difference, Formation, Tensile strength, Z direction strength

ABSTRACT: It has been unclear how fiber coarseness affect formation and the utilization of furnish strength in the machine-made paper (strength efficiency). In this work, the effect of softwood kraft fiber coarseness on formation and strength efficiency in twin-wire roll forming was examined in a pilot machine investigation.

A reduction in softwood kraft fiber coarseness from 0.21 to 0.17 mg/m, associated with a reduction in fiber grammage from 6.2 to 5.2 g/m^2, was found to have no significant effect on formation at the point of minimum shear during dewatering. The insignificant effect of reduced coarseness can be interpreted as the net result of two effects, namely, an increase in the number of fiber layers at a given grammage (favorable) and an increase in the flocculation tendency (unfavorable). While the effect of coarseness was negligible at the point of minimum shear, coarser fibers enabled larger improvement in formation through the jet-to-wire speed difference.

In correspondence to the insignificant effect on formation, fiber coarseness had a negligible effect on tensile strength efficiency and Z-strength at the point of minimum shear. The larger improvement in formation through the jet-to-wire speed difference for the coarser fibers was reflected in a favorable effect on Z-strength efficiency.

ADDRESSES OF THE AUTHORS:
Bengt Nordström (bengt.e.nordstrom@sca.com), SCA R&D Centre, P.O. Box 716, SE-851 21 Sundsvall, Sweden;
Lennart Hermansson (lennart.hermansson@ri.se), RISE Bioeconomy, P.O. Box 5604, SE-114 86 Stockholm, Sweden.
Corresponding author: Bengt Nordström

Introduction

Morphological fiber properties are considered responsible for 70–90% of the sheet property variations of chemical softwood pulps (Paavilainen 2002). Due to the difficulties in measuring cell (fiber) wall thickness, fiber coarseness (fiber mass per unit length) is usually employed for characterization of the fiber cross section. Coarseness and cell wall thickness are different properties but are often found to be correlated. For European and American softwood kraft pulps, Paavilainen (1993) found that 78% of the variation in coarseness was related to cell wall thickness.

At a given refining energy, low coarseness can be expected to promote tensile strength through high sheet density on account of the higher flexibility of thin-walled fibers. Low coarseness has a favorable effect on tensile strength also at a given density or bonding level (Page 1969). Low coarseness implies more fibers per unit mass of pulp and a higher number of bonds per unit fiber length at a given sheet density. This suggests a more efficient stress transfer in the fiber network and a more even stress distribution.

Whereas low fiber coarseness has a favorable effect on the tensile strength of handsheets, it is unclear how coarseness affects the utilization of the furnish strength in the machine-made paper (strength efficiency). A possible effect of coarseness on strength efficiency can be expected to be related to its effect on formation, as, all else being equal, a more even mass distribution should promote a more even stress distribution. A favorable effect on strength efficiency in twin-wire roll forming is observed when improving formation through headbox consistency (Nordström 2003d; Nordström, Hermansson 2016) or fiber length (Nordström, Hermansson 2017a). It should be pointed out, however, that there is no universal relationship between strength efficiency and formation. For example, tensile strength efficiency tends to decrease rather than increase when improving formation through blade pulses (Nordström 2003b; Nordström 2003e; Nordström 2006) or jet-to-wire speed difference (Nordström 2003a). This may be attributed to shear stresses deteriorating the deposited fiber mats and thereby counteracting the favorable effect of the formation improvement.

One may anticipate that fiber coarseness affect formation through two counteracting effects. On the one hand, lower fiber coarseness promotes lower fiber grammage (fiber mass per projected unit area) and, thereby, an increased number of fiber layers at a given sheet grammage, which has a favorable effect on formation (Norman 1986; Norman 1998). On the other hand, more fibers per unit mass suggest a higher tendency to fiber flocculation and an adverse effect on formation.

A possible effect of fiber coarseness on formation may be expected to affect not only tensile strength efficiency but also Z-strength efficiency. The relative increase was, in fact, larger for Z-strength efficiency than for tensile strength efficiency when the formation was improved through fiber length or headbox consistency in twin-wire roll forming of never-dried unbleached softwood kraft furnishes (Nordström, Hermansson 2017a).

The objective of this work was to investigate the effect of softwood kraft fiber coarseness on formation and strength efficiency in twin-wire roll forming. Whereas the two pulps employed for furnish preparation differed in both coarseness and fiber length, two furnishes with similar fiber length were obtained by using different refining conditions for the pulps.

Materials and Methods

The effect of softwood kraft fiber coarseness on formation and strength efficiency in twin-wire roll forming was studied in a pilot machine investigation at RISE Bioeconomy (former STFI and Innventia). General descriptions of the pilot machine system (FEX) have been given by Röding and Norman (1986) and Nordström (1995).

Three furnishes were examined over a wide range of jet-to-wire speed differences. The jet-to-wire speed difference was varied by varying the wire speed from 550 to 660 m/min while the headbox conditions were kept constant. This resulted in a change in grammage from 74 to 64 g/m^2 (averages for the three series).

Furnishes

Three furnishes, denoted "contorta", "sylvestris", and "sylvestris-cut", were prepared from two batches of never-dried unbleached softwood kraft pulp. No retention aid was added. *Table 1* shows properties of the three furnishes.

Contorta: The furnish contorta was prepared from a pulp chiefly based on *Pinus contorta* thinnings and with a kappa number of about 50. The pulp was sampled at a dry solids content of 10–15% at the pulp washing stage in the Obbola linerboard mill (SCA). Morphologic analysis revealed that the pulp had a content of 77% *Pinus contorta*, 20% *Pinus sylvestris,* and 4% *Picea abies* (average values for three separate pulp samples). The pulp was refined to a specific energy of 100 kWh/t at a specific edge load of 1.5 Ws/m and a consistency of 4% after adjustment to pH 9.0. Two-stage refining was used, and the two conical refiners had the same design (Jylhävaara JC-00) and were similarly operated (each stage introduced half of the refining energy). The rotational speed was 1000 r/min, and the fillings had a cutting edge length of 1.8 km/rev.

Sylvestris: The furnish sylvestris was prepared from a pulp chiefly based on *Pinus sylvestris* sawmill chips and with a kappa number of about 47. The pulp was sampled at a dry solids content of about 10% at the end of the pulp washing stage in the Munksund linerboard mill (SCA). Morphologic analysis revealed that the pulp had a content of 84% *Pinus sylvestris,* 12% *Picea abies*, and 4% hardwood (average values for three separate pulp samples).

The same two conical refiners that were employed for contorta were used in the preparation of sylvestris. After adjustment to pH 9.0, the pulp was refined to a specific energy of 160 kWh/t (half of the energy introduced in each stage) at a specific edge load of 1.5 Ws/m, a rotational speed of 1000 r/min, and a consistency of 4%.

Sylvestris-cut: The furnish sylvestris-cut was prepared from the same pulp batch that sylvestris was prepared from. The pulp used for both furnishes was filled into containers on one occasion, keeping track of the order in which the containers were filled. The pulp in every second container was used for the preparation of sylvestris, whereas the remaining pulp was used for the preparation of sylvestris-cut. This was done to minimize any difference between the pulps used for the two furnishes. In the preparation of sylvestris-cut, a 24-inch double-disc refiner (Beloit) was used in one stage. The rotational speed was 750 r/min, and the fillings had a cutting edge length of 6.13 km/rev and dams to reduce the flow in the grooves. After adjustment to pH 9.0, the pulp was refined to a specific energy of 160 kWh/t at a specific edge load of 2.5 Ws/m and a consistency of 4%.

Fiber coarseness for sylvestris-cut (not measured) is considered to be similar to the fiber coarseness for sylvestris. This is supported by the similarity in fiber width between the two furnishes (*Table 1*). Moreover, a greater reduction in coarseness during refining for one of the furnishes should have involved increased fines generation. The observation of only a minor difference in fines content (*Table 1*) between the two furnishes can therefore be taken as additional support for similar coarseness.

Forming

The forming roll (Nordström, Norman 1994a) had a diameter of 1.635 m. The roll wrapping angle was 77°. The vacuum in the three suction zones of the forming roll was –(2 to 3), –3, and –10 kPa, as given in MD.

The inner and outer wires were both of the sheet support binder (SSB) type. They had 1330 support points per cm^2 and were 2-shed on the paper side and 5-shed on the machine side. Both wires had a tension of 10 kN/m.

The hydraulic headbox employed had four tube rows and an inner width of 0.33 m. Except for the vane design, refer to Nordström (2003c) for a description of the headbox design. The present vanes were made of polycarbonate and had a length of 100 mm, a base thickness of 5 mm, and were tapered down to a thickness of 0.5 mm at the tip.

The volumetric headbox flow rate employed was 192 l/sm, and it was controlled by online measurement with a

Table 1 – Furnish properties. Average values based on three separate samples per furnish, with ranges for the three samples within parentheses. The water retention value (WRV) was measured after fines removal and adjustment to pH 7.8.

Furnish	Fiber length (mm)	Fiber curl index (%)	Fiber width (µm)	Coarseness (mg/m)	Fiber grammage (g/m^2)	WRV (g/g)	SR	Fines (%)
Contorta	1.94 (1.94–1.95)	15.2 (15.0–15.4)	33.0 (33.0–33.0)	0.173 (0.166–0.177)	5.2 (5.0–5.4)	1.7 (1.7–1.7)	18 (18–19)	5.5 (4.7–6.2)
Sylvestris	2.56 (2.55–2.56)	12.9 (12.7–13.3)	34.6 (34.3–34.8)	0.214 (0.212–0.217)	6.2 (6.2–6.2)	1.6 (1.6–1.6)	19 (19–19)	5.9 (5.5–6.1)
Sylvestris-cut	1.83 (1.82–1.84)	14.3 (14.1–14.6)	34.3 (34.2–34.4)	—	—	1.7 (1.7–1.7)	32 (31–33)	7.1 (7.0–7.1)

magnetic meter. The flow rate corresponded to headbox consistencies within a range of 0.39–0.46%. The first pass retention was 77–86%, with a tendency to higher retention at the lower wire speeds (higher grammages) and lower retention at the higher wire speeds (lower grammages).

Before the first experimental point of each jet-to-wire speed difference series, the jet speed was set for the point of minimum shear during dewatering to occur at a wire speed of 600 m/min. The headbox pressure was then kept constant over the speed difference series. A speed of the fiber suspension in the twin-wire nip (v) of 600 m/min, together with the wire tension (T=10 kN/m), the forming roll radius (R=1.635/2=0.8175 m), and the suspension density (ρ=1000 kg/m^3), gives a jet speed (u) of about 670 m/min using Bernoulli equation:

$$u = \sqrt{v^2 + \frac{2T}{\rho R}} \,. \qquad [1]$$

Together with the headbox flow rate, this jet speed corresponds to a jet thickness of 17 mm and a nozzle contraction ratio of 7. The nozzle contraction ratio is given by the upstream nozzle height of 130 mm, reduced by the total vane thickness (3×5=15 mm), in relation to the jet thickness.

The system temperature was 37–39°C and pH in the headbox 8.1–8.7.

Wet pressing and drying

The press section comprised one roll-press nip followed by two shoe-press nips. The roll-press nip was double-felted and comprised a suction top roll with a diameter of 1200 mm and a blind-drilled mating roll with a diameter of 1000 mm. A linear load of 60 kN/m was applied in the roll-press nip. The second and third nips were both single-felted shoe-press nips with shoe lengths of 260 mm and roll diameters of 1225 mm. The second nip had the press roll in the upper-position, and the third nip was inverted with respect to the second nip. The linear loads in the second and third nips were 700 and 1000 kN/m, respectively. The shoe-press design enabled online adjustment of the tilt, which represents the ratio between the load on the outgoing side and the load on the ingoing side. The tilt was 1.25 in the second nip and 1.35 in the third nip. Dry solids content after the press section was 37–41%.

The paper web was wound up after the press section, and the draw between wire section and winder was 3.1% through the whole investigation. The paper web was then dried on an off-line dryer with a single drying cylinder. Two longitudinal straps forced the dryer fabric and paper web against the glossy surface of the cylinder, which resulted in essentially restrained drying in both MD and CD.

Handsheets

For each furnish, conventional handsheets were prepared from three separate samples taken from the line feeding the pilot paper machine during the jet-to-wire speed difference series. pH of the pulp was adjusted to 7.8 before sheet making. The handsheets had a nominal oven-dry grammage of 60 g/m^2 and were made according to ISO 5269-1, except for the wet-pressing pressure. To reach a density of the handsheets similar to the density of the machine-made paper, the pressure employed (in both steps) was 500 kPa for contorta, 800 kPa for sylvestris, and 600 kPa for sylvestris-cut, whereas a pressure of 410 kPa is prescribed by the ISO method.

Analysis

The machine-made paper and the handsheets were pre-conditioned and conditioned according to ISO 187. Ambertec formation was measured according to SCAN-P 92:09. Apparent bulk density was measured following ISO 534 for the machine-made papers and ISO 5270 for the handsheets. Tensile strength and tensile stiffness were measured according to ISO 1924-3 and Z-strength according to ISO 15754.

Tensile strength efficiency is given by the geometric mean of the tensile indices in MD and CD of the machine-made paper in relation to the tensile index of handsheets prepared from the same furnish and with similar density. The geometric mean is used to represent the tensile strength of the machine-made paper, as it is an invariant with respect to the fiber orientation anisotropy for tensile strength (Htun, Fellers 1982). Z-strength efficiency is given by the Z-strength of the machine-made paper in relation to the Z-strength of the handsheets.

Fiber length was measured with the FiberLab instrument of Metso according to ISO 16065-1. The reported fiber length represents the length-weighted average of the contour length. The measurement also gave the fiber curl index (arithmetic average) and the fiber width (length-weighted average). Fiber coarseness was obtained from separate measurements with the FiberLab instrument following the procedure for removal of fines and debris and the method of obtaining samples described by Seth and Chan (1997). This included forming sheets with an oven-dry grammage of about 30 g/m^2 in a conventional handsheet mold. A minimum of two subsamples were measured, and the number of fibers (length >0.2 mm) measured per subsample exceeded 9400. Fiber grammage was calculated as fiber coarseness divided by fiber width.

The content of different wood species in the pulp was determined by morphologic analysis, with 500 fibers classified per sample. Kappa number was measured according to ISO 302 and drainability (SR number) according to ISO 5267-1. Fines content was measured by fractionation in a Britt drainage jar with a plate-hole diameter of 76 µm. The water retention value (WRV) was measured according to SCAN-C 62:00 (with test-pad former) after fines removal.

All confidence intervals were calculated with a confidence level of 95%.

Table 2 – Handsheet properties for the three furnishes. Average values, with ranges for the three samples within parentheses.

Furnish	Density (kg/m³)	Ambertec formation (√g/m)	Tensile index (kNm/kg)	Z-strength (kN/m²)
Contorta	726 (722–729)	0.36 (0.35–0.36)	93 (92–93)	848 (844–857)
Sylvestris	726 (721–730)	0.43 (0.43–0.44)	92 (91–92)	775 (770–780)
Sylvestris-cut	754 (750–758)	0.41 (0.41–0.42)	85 (85–85)	858 (856–861)

Results

The effect of softwood kraft fiber coarseness on formation and strength efficiency in twin-wire roll forming was evaluated in a pilot machine investigation. This involved examining three furnishes over a wide range of jet-to-wire speed differences. The furnish denoted "contorta" was prepared through gentle refining of pulp chiefly based on *Pinus contorta* thinnings, and the fibers of contorta had relatively low coarseness and short length. The furnish denoted "sylvestris" was prepared through gentle refining of pulp chiefly based on *Pinus sylvestris* sawmill chips, and the fibers of sylvestris had relatively high coarseness and long length. The difference in fiber coarseness between the furnishes was associated with a difference in fiber grammage. The furnish denoted "sylvestris-cut" was prepared through intensive refining of the pulp chiefly based on *Pinus sylvestris* sawmill chips for an average fiber length similar to that of contorta.

Table 2 shows properties for handsheets made from the three furnishes and with densities corresponding to those of the machine-made paper. The machine-to-handsheet ratio for the density was within a range of 0.99–1.03 for all experimental points. The density was similar for contorta and sylvestris, with a higher density for sylvestris-cut. Ambertec formation of the handsheets was significantly better for contorta than for sylvestris or sylvestris-cut, whereas the difference between sylvestris and sylvestris-cut was negligible. Tensile strength of the handsheets was similar for contorta and sylvestris, with lower tensile strength for sylvestris-cut despite higher density. Z-strength of the handsheets was substantially higher for contorta than for sylvestris, whereas contorta and sylvestris-cut showed similar Z-strength despite higher density for sylvestris-cut.

Table 3 shows the precision in the measurement of the mechanical properties of the machine-made paper.

Formation

Ambertec formation of the machine-made paper was substantially better for contorta than for sylvestris over the whole speed difference range (*Fig 1*), whereas sylvestris-cut and contorta showed similar formation at the point of minimum shear between fiber suspension and wire. The improvement in formation produced by the speed difference was larger for sylvestris and sylvestris-cut than for contorta. At large speed differences (positive or negative), sylvestris-cut showed significantly better formation than did contorta.

Anisotropy

The effect of the speed difference between fiber suspension and wire on anisotropy (MD/CD ratio for tensile stiffness) was similar for the three furnishes, and there were no clear differences between the minimum anisotropy levels (*Fig 2*).

Table 3 – Relative half-width of the confidence intervals for tensile strength, tensile stiffness, and Z-strength of the machine-made paper.

	Rel. half-width (%)
Tensile strength, MD	2.1–5.8
Tensile strength, CD	1.5–4.9
Tensile stiffness, MD	1.3–4.0
Tensile stiffness, CD	0.7–2.9
Z-strength	1.1–2.6

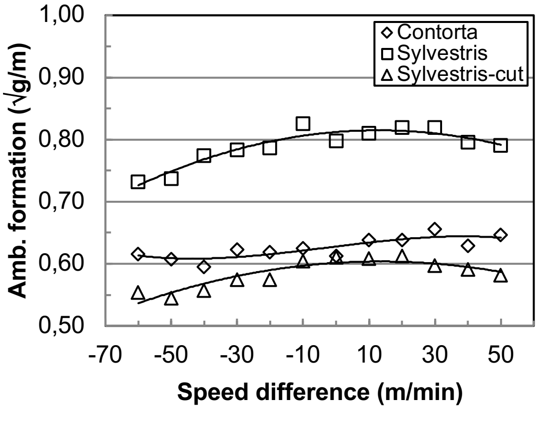

Fig 1 – Ambertec formation of machine-made paper vs. speed difference between fiber suspension and wire for the three furnishes. Confidence interval for individual sample points: ±(0.01–0.03) √g/m.

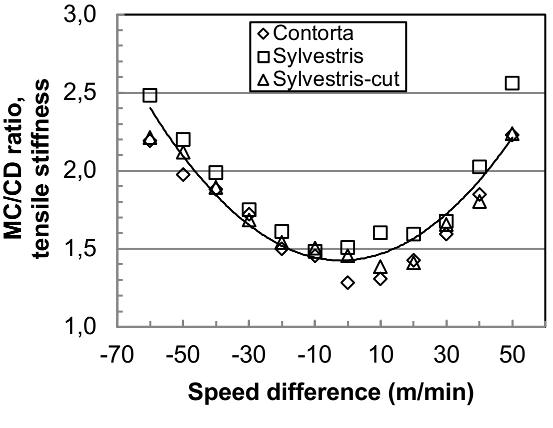

Fig 2 – MD/CD ratio for tensile stiffness of machine-made paper vs. speed difference between fiber suspension and wire for the three furnishes.

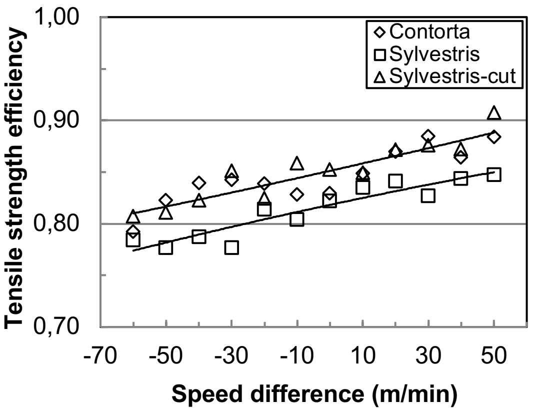

Fig 3 – Tensile strength efficiency vs. speed difference between fiber suspension and wire for the three furnishes.

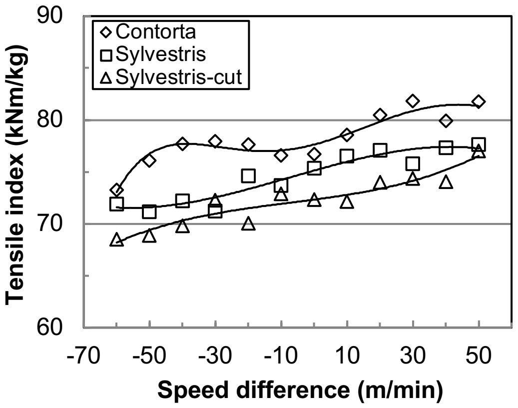

Fig 4 – Tensile index (geometric mean of the indices in MD and CD) of machine-made paper vs. speed difference between fiber suspension and wire for the three furnishes.

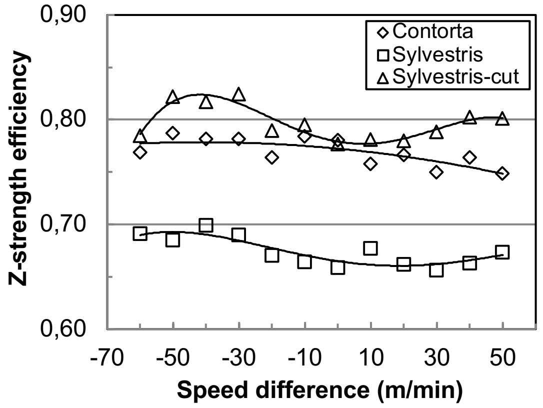

Fig 5 – Z-strength strength efficiency vs. speed difference between fiber suspension and wire for the three furnishes.

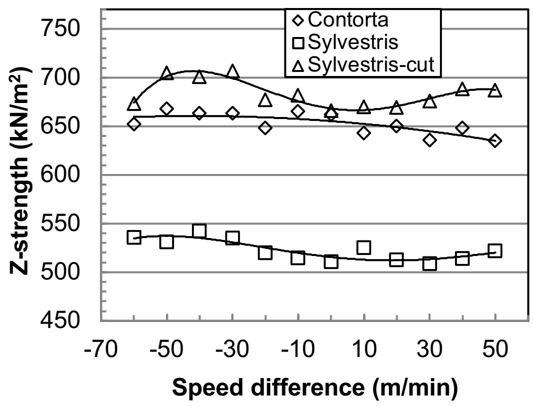

Fig 6 – Z-strength of machine-made paper vs. speed difference between fiber suspension and wire for three furnishes.

Tensile strength efficiency

Contorta and sylvestris-cut showed similar tensile strength efficiency over the whole speed difference range, whereas the tensile strength efficiency was lower for sylvestris (*Fig 3*). The result for tensile strength efficiency corresponds to the similarity in paper formation between contorta and sylvestris-cut and the worse formation for sylvestris.

Contorta resulted in machine-made paper with higher tensile strength than did sylvestris (*Fig 4*), in agreement with the higher strength efficiency for contorta and the similarity between contorta and sylvestris in handsheet strength. Despite a strength efficiency similar to that for contorta, sylvestris-cut produced paper with the lowest tensile strength, which is explained by the low tensile strength potential (low handsheet strength) of sylvestris-cut.

For all three furnishes, tensile index and tensile strength efficiency increased with increasing absolute speed difference (from –70 to 50 m/min), which is considered to be a reflection of the increase in grammage with increasing speed difference.

Z-strength efficiency

Contorta and sylvestris-cut showed higher Z-strength efficiency over the whole speed difference range than did sylvestris (*Fig 5*). Contorta and sylvestris-cut showed similar efficiency at the point of minimum shear, but the response to the speed difference differed. For sylvestris-cut, and to a lesser extent sylvestris, Z-strength efficiency increased with increasing speed difference (positive or negative) up to moderate speed differences. This increase in Z-strength efficiency corresponds to the more pronounced improvement in formation for sylvestris-cut and sylvestris than for contorta when increasing the speed difference.

The result for Z-strength of the machine-made paper is a reflection of the result for Z-strength efficiency but with an even larger relative difference between contorta and sylvestris-cut on the one hand and sylvestris on the other hand (*Fig 6*). This is related to the difference in the Z-strength of the handsheets.

Discussion

The jet-to-wire speed difference was changed by the wire speed for well-defined changes of the speed difference and unchanged headbox conditions over the speed difference curve. As a consequence, the grammage increased with increasing absolute speed difference. The increase in tensile index and tensile strength efficiency with increasing absolute speed difference is attributed to the increase in grammage. The comparison between the three furnishes should not have been affected, however, considering that the change in grammage was similar for all three furnishes.

The insignificant effect of a change in fiber coarseness (contorta vs. sylvestris-cut) on formation at the point of minimum shear during dewatering is interpreted as the net result of two counteracting effects. On the one hand, the lower coarseness of contorta was associated with lower fiber grammage. The relative difference in fiber grammage between the furnishes was nearly as large as the relative difference in coarseness, since the difference in fiber width was small. Lower fiber grammage implies a higher mean number of fiber layers at a given sheet grammage, which has a favorable effect on formation (Norman 1986). On the other hand, reduced coarseness can be expected to have involved an increased tendency to fiber flocculation on account of more fibers per unit mass.

The favorable effect of an increased number of fiber layers was observed in the handsheet formation of contorta versus sylvestris or sylvestris-cut. Handsheets are prepared with the fiber flocculation largely suppressed, which is consistent with the negligible effect of a change in fiber length (sylvestris-cut vs. sylvestris) on the handsheet formation. An insignificant effect of fiber length on handsheet formation was also observed in an earlier investigation (Nordström, Hermansson 2017a).

The insignificant effect of fiber coarseness on formation suggests that the difference in formation between contorta and sylvestris at the point of minimum shear was related to the difference in fiber length alone. Whilst the difference in formation was substantial at the present headbox consistency (ca. 0.4%), it should be observed that the relative difference in formation (and strength efficiency) related to a difference in fiber length increases with increasing headbox consistency (Nordström, Hermansson 2017a). One can thus expect that the relative difference in formation between contorta and sylvestris would be even larger at headbox consistencies higher than that presently employed. Correspondingly, one may anticipate a larger relative importance of increased fiber flocculation when reducing fiber coarseness at consistencies considerably higher than the present level.

The results suggest that higher fiber coarseness, regardless of fiber length, enables larger formation improvement through the jet-to-wire speed difference. Coarser fibers can be expected to be stiffer and may therefore form looser and weaker fiber flocs that are more easily broken when subjected to shear stresses introduced by the speed difference between fiber suspension and wire. The favorable effect of formation improvement through the jet-to-wire speed difference on Z-strength, but not on tensile strength, is in agreement with earlier results for never-dried unbleached softwood kraft pulp (Nordström, Hermansson 2017b).

The insignificant effect of fiber coarseness on formation at the point of minimum shear corresponded to an insignificant effect of coarseness on tensile strength efficiency and Z-strength efficiency. Note that the result for strength efficiency is considered to be unaffected by the difference in refining energy between contorta on the one hand and sylvestris and sylvestris-cut on the other. This is, as a change in refining energy, with an associated change in sheet density, has been shown to have no significant effect on strength efficiency (Nordström, Hermansson 2016).

Even though the effect of fiber coarseness on strength efficiency at the point of minimum shear is insignificant, fiber coarseness affects the strength of machine-made paper through its effect on the furnish strength (handsheet strength). The higher Z-strength at similar handsheet density for contorta versus sylvestris and the similarity in tensile strength despite the shorter fiber length of contorta are chiefly attributed to the lower coarseness of contorta, while a contribution from other factors is not excluded. The disadvantage of shorter fiber length for tensile strength of handsheets is demonstrated by the lower tensile strength for sylvestris-cut than sylvestris despite higher density. The adverse effect of a reduction in fiber length on tensile strength at similar density was exemplified for never-dried unbleached softwood kraft pulp in an earlier study (Nordström, Hermansson 2017a), which also demonstrated that Z-strength remains similar when changing fiber length. At a given density, lower coarseness can be expected to promote higher tensile strength and Z-strength through a more even stress distribution as a result of shorter free fiber segment length between bonds. The importance of coarseness is supported by a study of Paavilainen (1993) in which coarseness alone explained 80% of the variation in tensile strength of different European and American softwood kraft pulps.

The similarity in the MD/CD ratio for tensile stiffness between contorta and sylvestris-cut suggests that fiber coarseness has an insignificant effect on fiber orientation anisotropy. The relatively low anisotropy level at the point of minimum shear for all three furnishes is explained by the low nozzle contraction ratio of the headbox employed (Nordström, Norman 1994b; Nordström, Norman 1995). It may be noted that the effect of headbox nozzle contraction on anisotropy is larger for long softwood fibers than for short hardwood fibers (Nordström 2003a).

Conclusions

In twin-wire roll forming, a reduction in softwood kraft fiber coarseness from 0.21 to 0.17 mg/m, associated with a reduction in fiber grammage from 6.2 to 5.2 g/m^2, has no significant effect on Ambertec formation at the point of minimum shear during dewatering. This is the case at least at headbox consistencies of about 0.4%. The insignificant effect on formation can be interpreted as the net result of two effects, namely, an increase in the number of fiber layers at a given sheet grammage (favorable) and an increase in the flocculation tendency (unfavorable). For comparison, a reduction in fiber coarseness and fiber grammage produces a significant improvement in the formation of handsheets, which should reveal the effect of an increased number of fiber layers largely unaffected by fiber flocculation.

While the effect of fiber coarseness on formation is negligible at the point of minimum shear, coarser fibers enable larger improvement in formation through the jet-to-wire speed difference, possibly as a result of weaker fiber flocs.

Fiber coarseness has an insignificant effect on fiber orientation anisotropy, as evaluated over a wide range of jet-to-wire speed differences.

In correspondence to the insignificant effect on formation at the point of minimum shear, fiber coarseness has a negligible effect on tensile strength efficiency. A negligible effect is also noted for Z-strength efficiency at the point of minimum shear, whereas fiber coarseness affects the response of Z-strength efficiency to the jet-to-wire speed difference. The larger improvement in formation through the jet-to-wire speed difference for coarser fibers is reflected in a favorable effect on Z-strength efficiency.

Even though fiber coarseness has a negligible effect on formation and strength efficiency at the point of minimum shear, the strength of machine-made paper is affected by coarseness through an effect on the strength potential (handsheet strength).

Acknowledgments

Mr. Tommy Berglund (Dept. Engineer at SCA Munksund AB) and Mr. Olof Öhgren (former Senior Process Engineer at SCA Obbola AB) are thanked for organizing the supply of the pulp as well as for interesting discussions.

References

Htun, M. and Fellers, C. (1982): The invariant mechanical properties of oriented handsheets. Tappi 65(4): 113.

Nordström, B. (1995): Effects of headbox design and dewatering conditions on twin-wire forming of TMP. Dissertation. Dept. Pulp & Paper Technology, Royal Institute of Technology, Stockholm.

Nordström, B. (2003a): Effects of pulp type and headbox design on anisotropy and other sheet properties in twin-wire roll forming. Nord. Pulp Paper Res. J. 18(3): 288.

Nordström, B. (2003b): Effects of roll wrapping angle and headbox flow rate in twin-wire roll-blade forming of a linerboard furnish. Nord. Pulp Paper Res. J. 18(3): 255.

Nordström, B. (2003c): Fourdrinier versus twin-wire roll forming—effects on fiber orientation anisotropy and other sheet properties. Nord. Pulp Paper Res. J. 18(3): 262.

Nordström, B. (2003d): Influence of consistency in twin-wire roll forming of two recycled liner furnishes. Nord. Pulp Paper Res. J. 18(3): 303.

Nordström, B. (2003e): Twin-wire blade forming versus roll forming of a linerboard furnish—effects on tensile strength and formation. Nord. Pulp Paper Res. J. 18(3): 245.

Nordström, B. (2006): Twin-wire roll forming of mechanical base paper from three furnishes – effects on formation and mechanical properties. Nord. Pulp Paper Res. J. 21(3): 349.

Nordström, B. and Hermansson, L. (2016): Effect of refining on strength efficiency in twin-wire roll forming of never-dried unbleached softwood kraft pulp. Nord. Pulp Paper Res. J. 31(4): 624.

Nordström, B. and Hermansson, L. (2017a): Effect of fiber length on formation and strength efficiency in twin-wire roll forming. Nord. Pulp Paper Res. J. 32(1): 120.

Nordström, B. and Hermansson, L. (2017b): One-sided versus two-sided roll forming of never-dried softwood kraft pulp – effects on formation and strength efficiency. Nord. Pulp Paper Res. J. 32(3): 407.

Nordström, B. and Norman, B. (1994a): Development of the STFI-former. Nord. Pulp Paper Res. J. 9(3): 176.

Nordström, B. and Norman, B. (1994b): Influence on sheet anisotropy, formation, Z-toughness and tensile stiffness of reduced feed area to a headbox nozzle. Nord. Pulp Paper Res. J. 9(1): 53.

Nordström, B. and Norman, B. (1995): Effects of roll-blade and roll forming on formation, retention, mechanical properties and anisotropy—a preliminary comparison. J. Pulp Paper Sci. 21(7): J223.

Norman, B. (1986): The formation of paper sheets. In: Paper structure and properties. J.A. Bristow and P. Kolseth (eds.), Marcel Dekker, New York, 123.

Norman, B. (1998): Fibre coarseness (weight per unit length) should be replaced by fibre grammage (weight per unit area). Nord. Pulp Paper Res. J. 13(2): 166.

Paavilainen, L. (1993): Importance of cross-dimensioal fibre properties and coarseness for the characterisation of softwood sulphate pulp. Paperi Puu 75(5): 343.

Paavilainen, L. (2002): Fiber structure. In: Handbook of physical testing of paper (vol. 1), Marcel Dekker, 699.

Page, D.H. (1969): A theory for the tensile strength of paper. Tappi J. 52(4): 674.

Röding, S. and Norman, B. (1986): FEX, The new STFI experimental paper machine. Tappi J. 69(1): 94.

Seth, R.S. and Chan, B.K. (1997): Measurement of fiber coarseness with optical fiber length analyzers. Tappi J. 80(5): 217.

Manuscript received November 13, 2017
Accepted January 14, 2018