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Citation for the original published paper (version of record):

Nordström, B., Hermansson, L. (2017)

Effect of the ratio of softwood kraft pulp to recycled pulp on formation and strength efficiency in twin-wire roll forming

Nordic Pulp & Paper Research Journal, 32(2): 229-236

<https://doi.org/10.3183/NPPRJ-2017-32-02-p229-236>

Access to the published version may require subscription.

N.B. When citing this work, cite the original published paper.

Permanent link to this version:

<http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-32969>

Effect of the ratio of softwood kraft pulp to recycled pulp on formation and strength efficiency in twin-wire roll forming

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KEYWORDS: Furnish, Pulps, Mixtures, Twin wire machines, Formation, Tensile strength, Z direction strength

ABSTRACT: Paper furnishes often contain a mixture of a weak pulp with relatively short fibers and a strong pulp with relatively long fibers. Whereas increased proportion of the long-fiber pulp can be expected to impair formation, it has been unclear to what extent a change in formation through the pulp ratio affects the strength efficiency. (Strength efficiency is a measure of how well the strength potential of the furnish, as reflected by the handsheet strength, is utilized in the machine-made paper.)

This pilot machine investigation examined the effect on strength efficiency in twin-wire roll forming when changing formation through the ratio between softwood kraft pulp (long fibers) and recycled pulp (short fibers) in the furnish. For comparison, the effect of formation, as changed by headbox consistency, was evaluated. Tensile strength efficiency and Z-strength efficiency both decreased when the formation was deteriorated by increased softwood kraft content. The effect of a change in formation through the kraft content was similar to the effect of a corresponding change in formation through headbox consistency (headbox flow rate).

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Introduction

Paper products are commonly made from a mixture of pulps rather than from a single pulp. In one category of mixtures, softwood kraft pulp or another relatively strong pulp with long fibers is added to a relatively weak pulp with short fibers. Mixtures of this category are employed for kraftliner. Whereas the top ply typically contains softwood kraft pulp alone, the base ply may contain a mixture of softwood kraft pulp and recycled pulp (OCC) with relatively short fibers. The same category comprises furnishes for magazine paper (LWC and SC), which contain mechanical pulp (relatively short fibers) and softwood kraft pulp (or other chemical pulp) (Haarla 2000).

The softwood kraft pulp typically represents the more costly furnish component, and the kraft content is therefore usually restricted to what is required with respect to, for example, tensile strength. The softwood

kraft pulp may not only contribute with longer fibers but also with higher fiber strength and higher bonding (sheet density), all of which are of importance for tensile strength (Page 1969). For laboratory sheets, tensile strength (tensile stiffness, and compression strength) may be predicted with good approximation by using the rule of mixture, as demonstrated for a mixture with mechanical pulp by Fellers et al. (1983) and for a mixture with recycled pulp (OCC) by Nordström (2016). For machine-made paper, systematic results concerning the effect of softwood kraft content (or the content of other long-fiber pulp) on the tensile strength are hard to find in the literature. A change in the softwood kraft content may not produce the same relative change in tensile strength for handsheets and machine-made paper. The strength efficiency represents a measure of how well the furnish strength is utilized in the machine-made paper. The strength efficiency is given by the strength of the machine-made paper in relation to the strength of handsheets prepared from the same furnish and with a density similar to that of the machine-made paper (before calendering). How the strength efficiency is affected by the softwood kraft content is a highly relevant question, considering that the furnish cost represents a substantial part of the production cost for many grades (nearly 50% for kraftliner) and that efficient utilization of the furnish therefore is crucial.

An increase in the softwood kraft content (i.e., the long-fiber content) can be expected to result in higher fiber flocculation tendency and worse formation for machine-made paper (Peel 1999). All else being equal, it can be anticipated that worse formation, that is, a less uniform local mass distribution, reduces strength (and thereby strength efficiency) as a result of a more uneven stress distribution. Accordingly, improved formation through reduced headbox consistency promotes higher tensile strength efficiency in twin-wire roll forming, as demonstrated for recycled pulp (Nordström 2003c) and softwood kraft pulp (Nordström, Hermansson 2016). Improved formation through shorter softwood kraft fiber length has also been observed to promote higher strength efficiency (Nordström, Hermansson 2017). It should be observed, however, that there is no universal relationship between formation and tensile strength efficiency. For example, higher strength efficiency has not been observed when improving formation through the dewatering conditions, whether it involves a change from fourdrinier to roll forming (Nordström 2003b) or a change from roll to roll-blade or blade forming (Nordström 2003d; Nordström 2006). It is thus unclear how a change in formation through the softwood kraft content would affect tensile strength efficiency.

A change in formation through the softwood kraft content may also affect Z-strength efficiency. Whereas Z-strength of handsheets has been shown to be closely associated with bonding strength and unaffected by fiber dimensions when evaluated at a given density (Andersson 1978), the effect of formation has to be considered for machine-made paper. Z-strength efficiency in roll forming of softwood kraft furnishes was found to increase with improving formation through lower headbox consistency or reduced kraft fiber length, and the relative effect of a change in formation was larger for Z-strength efficiency than tensile strength efficiency (Nordström, Hermansson 2017).

The main objective of this work was to investigate how the tensile strength efficiency and Z-strength efficiency in twin-wire roll forming is affected when changing formation through the softwood kraft content in a mixture with recycled pulp. A secondary objective was to compare the effect of a change in formation through the softwood kraft content and the effect of a change in formation through headbox consistency.

Materials and Methods

The effect of the ratio between softwood kraft pulp and recycled pulp on strength efficiency in twin-wire roll forming was studied in a pilot machine investigation at RISE Bioeconomy. General descriptions of the pilot machine system have been given by Röding and Norman (1986) and Nordström (1995).

A series of five kraft contents (0, 25, 50, 75, and 100%) was examined at two volumetric headbox flow rates (111 and 177 l/sm). Three additional flow rates were included at a kraft content of 50%. In total, five different flow rates were thus examined at a kraft content of 50%. Different flow rates were included for a comparison of the effect of changing formation through the kraft content with the effect of changing formation through headbox consistency.

The grammage of the machine-made paper was 64–70 g/m².

Furnish

The softwood kraft pulp employed was never-dried and unbleached and had a kappa number of about 52. The kraft pulp had a content of 71% *Pinus sylvestris*, 12% *Pinus contorta*, and 18% *Picea abies* (averages of two samples). The pulp was sampled at a dry solids content of 10–15%, immediately after the pulp washing stage in the Obbola linerboard mill (SCA). All pulp required for the investigation 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 kraft content series with the high headbox flow rate, whereas the rest of the pulp was used for the remaining points. This was done to minimize the influence of a possible variation in unrefined pulp properties.

The softwood kraft pulp was refined to a specific energy of 120 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.

The refined kraft pulp had a drainability of 19–20 SR, a fiber length (length-weighted average) of 2.2 mm, a fiber curl index of 15.5–16.0%, and a fines content of 5–6 %. After fines removal and adjustment to pH 7.8, a water retention value (WRV) of 1.65–1.69 g/g and a fiber saturation point of 1.44–1.49 g/g were measured.

The recycled pulp was prepared from paper rolls made from old corrugated containers (OCC). The rolls were slushed at a temperature of 60°C and a consistency of about 4%. After adjustment to pH 7.8, the recycled pulp was refined at a consistency of about 4% and a specific edge load of 0.5 Ws/m to a specific refining energy of 25 kWh/t. The refining was carried out as two-stage refining using the same two refiners that were employed for the kraft pulp. The refined recycled pulp had a drainability of 45 SR, a fiber length (length-weighted average) of 1.4 mm, and a fines content of 22–23%.

The ash contents of the pulps were not measured, but data for the machine-made paper with 100% recycled pulp or 100% kraft pulp (Fig 13) suggest that the ash content was approximately 9% in the recycled pulp and 1% in the kraft pulp. The higher ash content in the recycled pulp reflects the content of inorganic fillers in the recycled paper.

As retention aid, Hydrocol (cationic polymer in combination with Bentonite) was used. For 100% recycled pulp, the cationic polymer (Percol 3035) was dosed at a rate of 500 g/ton immediately after the deaerator (before the headbox feed pump), whereas the Bentonite was dosed at a rate of 2000 g/ton after the headbox feed pump. The dosage rate for both polymer and Bentonite was reduced in proportion to the content of recycled pulp when increasing the kraft content, with a dosage rate of zero for both components at a kraft content of 100%.

Forming

The forming roll (Nordström, Norman 1994) had a diameter of 1.635 m, and the roll wrapping angle was 77°. The vacuum in the three suction zones of the forming roll was –3, –3, and –10 kPa, as given in MD. The inner and outer wires were both plastic forming wires of the sheet support binder (SSB) type. They had 1330 support points per cm² and were 2-shed on the paper side and 5-shed on the machine side. The wire tension was 10 kN/m (both wires) and the wire speed 600 m/min. The system temperature was 40–43°C and pH in headbox 7.7–8.2.

The first series of softwood kraft contents was run at a volumetric headbox flow rate of 177 l/sm, as measured with a magnetic flow meter. This flow rate corresponded to a range of headbox consistencies from 0.48% (100% softwood kraft pulp) to 0.57% (100% recycled pulp) and to a range of first pass retention values from 69% (100% recycled pulp) to 76% (100% softwood kraft pulp).

The second series of softwood kraft contents was run at a volumetric headbox flow rate of 111 l/sm. This flow rate corresponded to a range of headbox consistencies from 0.68% (100% softwood kraft pulp) to 0.79% (100% recycled pulp) and to a range of first pass retention values

from 72% (100% recycled pulp) to 85% (100% softwood kraft pulp).

At a softwood kraft content of 50%, three additional headbox flow rates were run, 141, 98, and 88 l/sm. In total, five flow rates over a range from 177 to 88 l/sm were thus examined at a kraft content of 50%. This flow rate range corresponded to a range of headbox consistencies from 0.50 to 1.0% and to a range of first pass retention values from 70 to 78%.

Before the first experimental point of each kraft content series, the jet speed was set for a speed difference between fiber suspension and wire of about $-(15 \text{ to } 20) \text{ m/min}$ in relation to the point of minimum shear. The headbox pressure was then kept constant over the kraft content series. The headbox pressure was unchanged when running the three additional headbox flow rates at a kraft content of 50% directly after the kraft content series with the low flow rate.

The hydraulic headbox employed had four tube rows and an inner width of 0.33 m. Except for the vane design, refer to Nordström (2003b) 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 to a thickness of 0.5 mm at the tip. The change in the headbox flow rate from 177 to 88 l/sm corresponded to a change in jet thickness from 16 to 8 mm. The upstream nozzle height of 130 mm, reduced by the total vane thickness ($3 \times 5 = 15 \text{ mm}$), and the jet thickness range give a range for the nozzle contraction ratio from 7 to 14. The effect of a change in nozzle contraction ratio on formation is negligible when using kraft pulp (Nordström 2003a) or recycled pulp (Nordström 2003b).

Wet pressing and drying

The press section comprised one roll press nip followed by two shoe press nips. The roll nip was double-felted and had 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 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. 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. The dry solids content after the press section went from 48–49% at a kraft content of 0% (100% recycled pulp) to 39% at a kraft content of 100%, with similar values for the different headbox flow rates.

The paper web was wound up after the press section, and the draw between wire section and winder was 3.1%. 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.

Handsheet preparation

For each experimental point, conventional handsheets were prepared from samples of the furnish fed to the paper machine. pH of the pulp was adjusted to 7.8 before sheet making. The handsheets had a nominal oven-dry grammage of 60 g/m² and were made with white-water recirculation. ISO 5269-3 was followed, except for the wet-pressing pressure. A pressure of 600 kPa (same pressure in both steps) was used for the kraft content series with the high headbox flow rate (177 l/sm) to obtain a density of the handsheets similar to the density of the machine-made paper. A pressure of 700 kPa was used for the remaining points.

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 according to ISO 534 for the machine-made papers and according to ISO 5270 for the handsheets. Tensile strength was measured according to ISO 1924-3 and Z-strength according to ISO 15754. Ash content was determined according to ISO 1762.

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 the 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 fiber length measurements also gave the fiber curl index. 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. The fiber saturation point (FSP) was also measured after fines removal and by a solute exclusion technique corresponding to that described by Stone et al. (1968).

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

Fig 1 – Fiber length (length-weighted average) vs. softwood kraft content for the two series with different headbox flow rates.

Fig 2 – Ambertec formation of machine-made paper vs. softwood kraft content for the two series with different headbox flow rates. Confidence interval for individual sample points: $\pm(0.01-0.02) \sqrt{g/m}$.

Fig 3 – Ambertec formation of handsheets vs. softwood kraft content for the two series with different headbox flow rates. Confidence interval for individual sample points: $\pm(0.01-0.02) \sqrt{g/m}$.

Fig 4 – Apparent bulk density of machine-made paper vs. softwood kraft content for the two series with different headbox flow rates.

Results

The effect of formation on strength efficiency in twin-wire roll forming when changing formation through the softwood kraft content in a mixture with recycled pulp was studied in this pilot machine investigation. A series of kraft contents from 0 to 100% were examined at two headbox flow rates. The low flow rate (111 l/sm) corresponded to a headbox consistency of 0.8% for 100% recycled pulp and to a consistency of 0.7% for 100% softwood kraft pulp. The high flow rate (177 l/sm) corresponded to a headbox consistency of 0.6% for 100% recycled pulp and to a consistency of 0.5% for 100% softwood kraft pulp. In addition, a series of headbox flow rates from 88 to 177 l/sm, corresponding to headbox consistencies from 0.5 to 1.0%, were included at a kraft content of 50%.

The fiber length (length-weighted average) differed substantially between the recycled pulp and the softwood kraft pulp, and it showed a linear increase with increasing kraft content (Fig 1). The increase in fiber length was reflected in the Ambertec formation number of the machine-made paper, which increased with increasing kraft content and showed a higher rate of increase at the low than the high headbox flow rate (Fig 2). By contrast, the kraft content had no appreciable effect on the formation of handsheets prepared from the furnish samples taken during the pilot machine investigation (Fig 3).

The density of the machine-made paper increased linearly with increasing kraft content (Fig 4). The density was higher for the series with the low flow rate than for the series with the high flow rate. The difference in density between the two series did, however, not affect the strength efficiency, since the handsheets prepared for the evaluation of strength efficiency were wet-pressed to a density similar to that of the machine-made paper. The machine-to-handsheet ratio for density was within a range of 1.00–1.03 for all experimental points.

Refer to Table 1 for information on the precision in the measurement of the mechanical properties.

Table 1 – Relative half-width of the confidence intervals for the mechanical properties. Confidence level: 95%.

Property	Rel. half-width (%)
	Machine-made paper
Tensile strength, MD	2.7–6.7
Tensile strength, CD	1.6–3.2
Z-strength	1.3–4.6
	Handsheets
Tensile strength	1.8–3.2
Z-strength	1.0–1.9

Fig 5 – Tensile index of handsheets vs. softwood kraft content for the two series with different headbox flow rates.

Fig 6 – Tensile index of machine-made paper vs. softwood kraft content for the two series with different headbox flow rates.

Fig 7 – Tensile strength efficiency vs. softwood kraft content for the two series with different headbox flow rates.

Fig 8 – Tensile strength efficiency vs. Ambertec formation. The two softwood kraft content series shown together with the headbox flow rate series (kraft content: 50%).

Fig 9 – Z-strength of handsheets vs. softwood kraft content for the two series with different headbox flow rates.

Tensile strength

Tensile strength of handsheets prepared from the furnish samples taken during the pilot machine investigation showed a nearly linear increase with increasing kraft content (Fig 5). The tensile strength was similar for the two series with different headbox flow rates despite the fact that the handsheets for the series with the low flow rate were made with higher density in correspondence to the higher density of the machine-made paper for that series.

Tensile strength of the machine-made paper, which was represented by the geometric mean of the strength in MD and CD, increased with increasing kraft content and showed a higher rate of increase for the high than the low headbox flow rate (Fig 6). Tensile strength efficiency decreased with increasing kraft content and showed a higher rate of decrease for the low than the high headbox

flow rate (Fig 7). When plotting tensile strength efficiency as a function of formation, the two kraft content series and the flow rate series (kraft content: 50%) fell on a common curve (Fig 8). Tensile strength efficiency was thus similarly affected whether changing formation through the kraft content or the headbox consistency.

Z-strength

Z-strength of handsheets showed a pronounced increase with increasing kraft content (Fig 9). The Z-strength of the handsheets tended to be higher for the series with the low than the high headbox flow rate, which corresponds to the density difference between the two series. In contrast to the Z-strength of handsheets, the Z-strength of machine-made paper showed a slight decrease with increasing kraft content for the high headbox flow rate and a pronounced decrease with increasing kraft content for the low flow rate (Fig 10).

Z-strength efficiency decreased with increasing kraft content, and the rate of decrease was higher for the low than the high headbox flow rate (Fig 11). When plotting Z-strength efficiency as a function of formation, the two kraft content series and the flow rate series (kraft content: 50%) fell on a common curve (Fig 12). Z-strength efficiency was thus similarly affected whether changing formation through the kraft content or the headbox consistency. It should be observed that a given change in formation produced a substantially larger relative change in Z-strength efficiency than in tensile strength efficiency.

Fig 10 – Z-strength of machine-made paper vs. softwood kraft content for the two series with different headbox flow rates.

Fig 12 – Z-strength efficiency vs. Ambertec formation. The two softwood kraft content series shown together with the headbox flow rate series (kraft content: 50%).

Fig 11 – Z-strength efficiency vs. softwood kraft content for the two series with different headbox flow rates.

Fig 13 – Ash content vs. softwood kraft content for machine-made paper (M) and handsheets (H). The two softwood kraft content series shown together with the headbox flow rate series (kraft content: 50%).

Ash content

There was a systematic difference in the ash content between the handsheets and the machine-made paper, with lower ash content at a given kraft content for the handsheets, whereas similar ash content was noted for the different experimental series (Fig 13). The difference in ash content was largest at 100% recycled pulp and decreased linearly with increasing kraft content to a negligible difference at 100% kraft pulp.

Discussion

Higher ash content in the machine-made paper than the handsheets at high contents of recycled pulp indicates a higher content of the inorganic fillers coming with the recycled pulp. The higher filler (ash) content is attributed to higher wire retention related to the use of retention aid on the pilot machine.

The handsheets were prepared with white-water recirculation for a higher proportion of fillers (and fines) in the pulp fed to the sheet former to be captured in the handsheets. Before making the sheets used for testing, the ISO method followed requires that a number of handsheets are first made (and discarded) to attain steady state in grammage. However, steady state in grammage does not exclude lower filler content in the handsheets than in the pulp fed to the former. With low wire retention, fillers may accumulate in the white-water system. This may explain the lower ash (filler) content in the handsheets than the machine-made paper.

Strength is adversely affected by ash (fillers). The lower ash content in the handsheets than the machine-made

paper therefore suggests that tensile strength and Z-strength of the handsheets were somewhat higher than they would have been with an ash content in the handsheets similar to that in the machine-made paper. This, in turn, suggests that tensile strength efficiency and Z-strength efficiency were somewhat lower than they would have been with an ash content in the handsheets similar to that in the machine-made paper. As the difference in ash content was largest at 100% recycled pulp and negligible at 100% kraft pulp, the effects on handsheet strength and strength efficiency should have been largest at 100% recycled pulp and negligible at 100% kraft pulp. With an ash content in the handsheets similar to the ash content in the machine-made paper, one would thus expect an even more pronounced increase in tensile strength efficiency and Z-strength efficiency with increasing content of recycled pulp (i.e., steeper slopes of the curves in Fig 7–8 and Fig 11–12). Nevertheless, the principal outcome of the investigation is not considered to have been affected by the difference in ash content between the machine-made paper and the handsheets.

The change in the formation of machine-made paper through a change in the softwood kraft content was associated with a change in average fiber length and is considered closely related to a change in the fiber flocculation tendency of the furnish. The formation of handsheets is not expected to be significantly affected by the flocculation tendency of the furnish, as an extremely low forming consistency suppresses fiber flocculation in handsheet preparation. Accordingly, the kraft content had an insignificant effect on handsheet formation. The

present results are in agreement with those of an earlier investigation in which two furnishes with different fiber length were prepared from the same batch of softwood kraft pulp by using different refining conditions (Nordström, Hermansson 2017). The handsheet formation was unaffected by the fiber length, and the change in the formation of the machine-made paper is solely attributed to a change in flocculation tendency.

The effect on tensile strength efficiency and Z-strength efficiency related to the change in formation through fiber length was similar to the effect of a corresponding change in formation through headbox consistency. Indeed, it seems reasonable that the effect on tensile strength efficiency and Z-strength efficiency related to a change in formation through the flocculation tendency is similar whether the flocculation tendency is changed by the furnish or headbox consistency. It is expected that a change in formation through the flocculation tendency of the furnish by other means than the softwood kraft content or the kraft fiber length produces a similar effect on tensile strength efficiency and Z-strength efficiency.

The present results show the importance of considering the effect on strength efficiency when evaluating furnishes. The difficulty of predicting the strength of machine-made paper from handsheet results alone is demonstrated by the Z-strength of machine-made paper and handsheets going in opposite directions when increasing the softwood kraft content but also by the substantially smaller relative increase in tensile strength for the machine-made paper than the handsheets. That handsheet results alone may be misleading for the strength of machine-made paper was observed also in the investigation concerning the effect of fiber length of softwood kraft furnishes (Nordström, Hermansson 2017). The increase in the tensile strength of handsheets produced by an increase in fiber length was reflected in an increase in the tensile strength of machine-made paper at low headbox consistencies, whereas the tensile strength of machine-made paper remained similar at consistencies above 0.5%. This was related to a faster decrease in tensile strength efficiency with increasing headbox consistency when increasing the fiber length.

Conclusions

Impaired formation in twin-wire roll forming through increased ratio between softwood kraft pulp and recycled pulp in the furnish is associated with an increase in average fiber length, and it is considered closely related to an increase in the flocculation tendency of the furnish. Impaired formation through the softwood kraft content reduces tensile strength efficiency, and tensile strength efficiency is similarly affected whether the formation is changed by the softwood kraft content or the headbox consistency. Impaired formation through increased softwood kraft content also reduces Z-strength efficiency, and Z-strength efficiency is similarly affected whether the formation is changed by the softwood kraft content or the headbox consistency. The relative effect of formation is larger for Z-strength efficiency than for tensile strength efficiency. The observed effects on tensile strength efficiency and Z-strength efficiency are in agreement with earlier results concerning a change in flocculation

tendency and formation through the softwood kraft fiber length.

The reduction in tensile strength efficiency with increasing softwood kraft content is reflected in a smaller relative increase in tensile strength for machine-made paper than for handsheets made of the furnish. The reduction in Z-strength efficiency with increasing softwood kraft content may reduce the relative increase in the Z-strength of the machine-made paper to the extent that it shows a decrease despite a substantial increase in the Z-strength of handsheets made from the furnish.

The demonstrated effect on tensile strength efficiency and Z-strength efficiency of a change in formation through the flocculation tendency of the furnish shows the importance of considering the effect on strength efficiency when evaluating furnishes.

Acknowledgments

Mr. Olof Öhgren (former Senior Process Engineer at SCA Obbola AB) is thanked for organizing the pulp supply as well as for interesting discussions.

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Manuscript received February 27, 2017

Accepted May 4, 2017