Effects of kappa number variability on pulp properties

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ABSTRACT

Documented pulp uniformity issues are available for the pulp and paper industry, but no clear understanding exists for the effect of nonuniformity on pulp properties. The project examines effects of nonuniformity by comparing pulp with variable kappa number distributions for bleachability and mechanical properties. Two mixtures with different kappa number distributions were compared with a uniform control pulp with the same average kappa number with analysis for brownstock strength and fiber morphology. The pulps were also bleached using ECF and TCF bleaching sequences. The pulps in this study did not show significant differences in strength or bleachability compared with the control pulp. Some limited differences existed in brownstock strength. The laboratory pulping and bleaching conditions were too mild to produce the negative effects that traditionally affect fiber strength. The pulps in this study therefore showed limited differences compared with the control pulp. Intrinsic fiber strength was maintained. Even with kappa number variability, all the pulps behaved similarly.

Application:

No differences in brownstock strength or bleachability for the mixtures tested occurred when mechanical factors in a pulp are minimized. Lignin content alone does not have a negative impact on fiber performance.

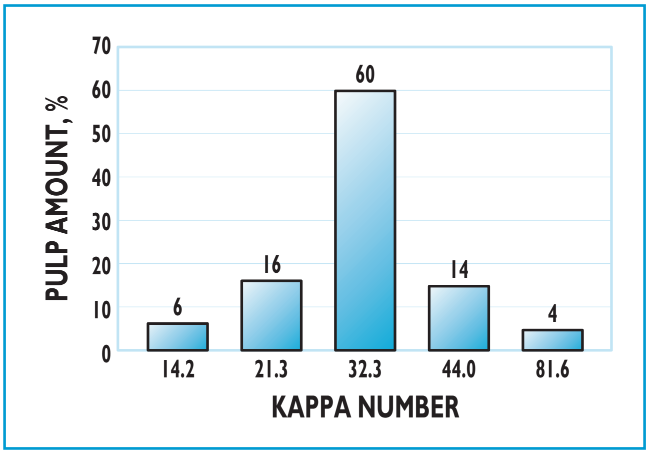
Achieving perfectly uniform pulp in a mill is difficult. Every batch of pulp comes from a different source and may contain various amounts of knots and debris. Besides the effects of the raw material, the digesters themselves can have performance deficiencies including uneven or inadequate liquor distribution, inefficient pre-steaming, and poor chip impregnation *(1)*.

With all these possible conditions creating nonuniform pulp, many documented cases of nonuniformity exist. A density gradient column may be used to determine the kappa number for each fiber and establish a kappa number distribution for a pulp mixture. Mill pulps show a larger standard deviation in lignin content than more uniform laboratory pulps *(2)*. In recent years, MacLeod and others have used hanging baskets to measure the variability of kappa number in different areas within a digester *(3)*. With these baskets, pulp uniformity correlated with damage resistance during a digester blow. More uniform pulp is more likely to resist damage from a blow. MacLeod also showed that pulp strength loss resulted from a digester blow by comparing samples from points within the digester *(3)*.

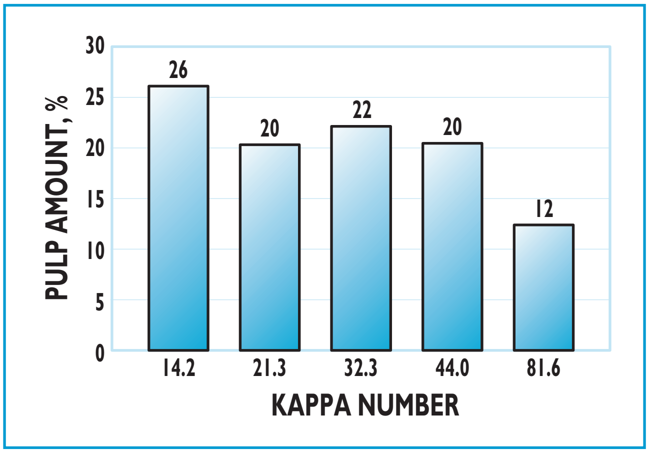
Since pulp uniformity is a concern in mills, companies have developed new pulping processes to produce uniform pulp. Kamyr extended modified continuous cooking (EMCC) is a pulping process that gives lower target kappa numbers but maintains brownstock pulp strength. If a mill could produce a lower kappa pulp by reducing the higher lignin fraction, the pulp would be easier to bleach and would therefore save money for the mill. New pulping technologies use the idea of pulp uniformity.

What effect does uniformity have on pulp properties and bleachability? Previous work has shown that nonuniform pulp is weaker and harder to bleach *(4, 5)*. Tichy and Procter compared pulp with different standard deviations of lignin content. The nonuniform pulp required more chlorine to reach the same permanganate number up to the CE stage using a CEHDED bleaching sequence. Comparing non-Gaussian distribution pulps showed that a nonuniform mixture had a decrease in bleach and brownstock strength and a higher chlorine demand. Hunt and Hatton measured the bleaching rates of pulps with varying lignin concentrations using a CED bleaching sequence *(5)*. A higher lignin pulp was harder to bleach than a lower lignin pulp. Kappa number variation should consequently be minimum. Higher lignin pulp required more chemical to achieve the same brightness endpoint.

An inadequate understanding still exists for what kappa variability does to pulp quality. Although a digester blow inflicts more damage on nonuniform pulp than uniform pulp, is uniform pulp intrinsically stronger than nonuniform pulp even without exposure to the damage of a digester blow? Past work showed that bleached nonuniform pulp was weaker and required more bleaching chemical. That work did not investigate why the nonuniform pulp was weaker. The research primarily used chlorine as the main bleaching chemical. Such chlorine use is no longer feasible. With most mills today switching their bleach plants to elemental chlorine free (ECF) and



1. Kappa number distribution of moderately uniform pulp



2. Kappa number distribution of poorly uniform pulp

totally chlorine free (TCF) bleaching sequences, the question is whether this kappa variability problem is worse without chlorine use.

OBJECTIVE AND APPROACH

This work investigated the effect of kappa number variability on pulp performance. A question that arose concerned the effect of kappa number variability on pulp properties and bleachability when the processing does not damage the fibers. In this study, the wood was carefully pulped to avoid detrimental effects to the fiber while still targeting different final kappa numbers. The raw material underwent scrupulous screening to obtain the optimum chip size of 4–6 mm. Specific pulping conditions used prevented depletion of cooking chemicals, lignin condensation, and overcooking. The ultimate goal was to remove the lignin selectively without affecting the integrity of the fibers.

Using the uniform pulping conditions, five kappa numbers of 10–80 were targeted. The kappa no. 30 pulp was used as the most uniform or control pulp. Two mixtures were created with the same average kappa number but with different distributions of the five pulps. The pulps underwent testing for strength and fiber morphology characteristics. The control pulp and the two mixtures were bleached under constant bleaching conditions using ECF and TCF bleaching sequences. The bleached pulps were also tested for strength and fiber morphology characteristics.

Pulp	Kappa no.	*H*-factor
1	14.2	1853
2	21.3	1250
3	32.3	800
4	44.0	625
5	81.6	360

I. Kappa numbers and H-factors of pulps before blending

MATERIALS AND METHODS

Five uniform pulps varying from kappa no. 14 to kappa no. 82 were produced. Douglas-fir chips were screened with a 6-mm thickness screen and accepted on a 7-mm round screen to remove any excessively thick chips, pins, and fines. Hand sorting removed compression wood and bark. Except the time of the cook, pulping conditions were constant *(6)*: 6/1 L/kg liquor/wood ratio (L/W), 24.8% effective alkali (as Na_2O), and a 40% sulfidity based on active alkali (AA). The chips were pre-steamed for 5 min at atmospheric pressure before the cooking liquor addition. The digester was ramped for 90 min to obtain the final cooking temperature of 160°C. Five different kappa values were targeted for the project. **Table I** contains the H-factors and measured kappa numbers. Kappa number measurement used TAPPI T235 cm-85.

Using these five uniform pulps, two mixtures were created that varied in their kappa number distribution. The two mixtures had the same average kappa no. 32, but they varied in their distributions of the starting pulps as **Figs. 1 and 2** show.

Stages	D_0	E_0	D_1
Charge	2.95% ClO_2	0.4% NaOH	0.60% ClO_2
Time, min	60	60	180
Temperature, °C	50	85	70
Consistency, %	10	5.5	10

II. ECF bleaching conditions

Stages	O_2	Q	Z	P
Charge	1.5% NaOH	0.5% DTPA	1.1% O_3	3% H_2O_2
Time	1 h	10 min	80 s	150 min
Temperature, °C	105	55	25	90
Consistency, %	5.5	5	10	12
NaOH, %	-	-	-	2.5
$MgSO_4$, %	0.5	-	-	0.5
DTPA, %	-	-	-	0.5

III. TCF bleaching conditions

The moderately uniform mixture mimicked typical pulp. The poorly uniform mixture was more extreme. The two mixtures were compared with a uniform original pulp having the same kappa no. 32. The kappa no. 32 pulp was the most uniform pulp or the control pulp. As MacLeod showed, a pulp with a kappa value from the low 20s to the middle 30s is the strongest softwood kraft pulp when compared with other pulps with a smaller or larger value of lignin *(7)*.

The two brownstock mixtures and the control pulp were analyzed for fiber morphology and physical strengths. The pulps were analyzed for PFI refining at 0, 500, 1500, 3000, and 8000 revolutions. CSF was determined using TAPPI method T 205. The brownstock pulp was tested for wet zero-span tensile index strength on the unrefined pulp. The tear strength and bulk properties were tested at all the refining levels. The pulps' tear and tensile strengths were measured using TAPPI T 414 and T 494, respectively. Fiber morphology data was measured with a Fiber Quality Analyzer (FQA) and the Kajaani FS100 (TAPPI T 271).

The pulps were bleached using a DEOD bleaching sequence. A duplicate bleach tested reproducibility. A target brightness of 85 was chosen to avoid the region of the brightness scale where the addition of more chemical produces little change in brightness. **Table II** shows the conditions used for the ECF bleaching sequence.

The chlorine dioxide bleaching used bag cooks in a hot-water bath. The pulps were washed and screened after each stage. The alkaline extraction stage used a commercially available digester at 35 psi. The second chlorine dioxide stage also used bag cooks in a hot-water bath.

The brightness value was determined with the GE brightness scale (TAPPI T218 om-83). The kappa numbers and viscosity were tested after the alkaline stage and after the last chlorine dioxide stage using TAPPI 246 and T 230, respectively.

The TCF bleaching sequence in this study was an OQZP. **Table III** shows the bleaching conditions.

The oxygen bleaching used a commercially available digester at 100 psi. The pulp was chelated before ozonation to remove any metals. The pulp was chelated with diaminetrietylenepentaacetic acid (DTPA) at pH 4–5. The ozone bleaching used 10% consistency in a commercially available high intensity mixer and reactor. A commercially available generator produced the ozone. Two-hundred grams of pulp were used with a total mixing time of 80 s. The peroxide bleaching used bag cooks in a hot-water bath.

Target kappa no.	Kappa value	Yield, %	Rejects, %	Time at 160°C, min	*H*-factor
10	14.2	44.0	0.05	275	1853
20	21.3	46.7	0.04	176	1250
30	32.4	49.6	0.07	112	800
40	44.0	49.6	0.12	85	625
80	81.6	54.4	0.47	46	360

IV. Results of kraft cooks at various target kappa numbers

Pulp	Weight mean curl	WAFL, mm	Kink index	Kink angle	Coarseness, mg/100m
Kappa no. 14	0.067	3.04	0.62	23.5	24.2
Kappa no. 82	0.059	3.22	0.52	19.7	32.1
Uniform	0.067	3.07	0.58	22.8	26.6
Moderate	0.066	3.09	0.57	20.9	27.0
Poor	0.068	3.07	0.58	22.2	25.7

V. Brownstock mixture and starting pulp fiber morphology data

Pulp	Capillary viscosity, mPa·s
Uniform	63.2
Moderately uniform	51.2
Poor uniform	40.3

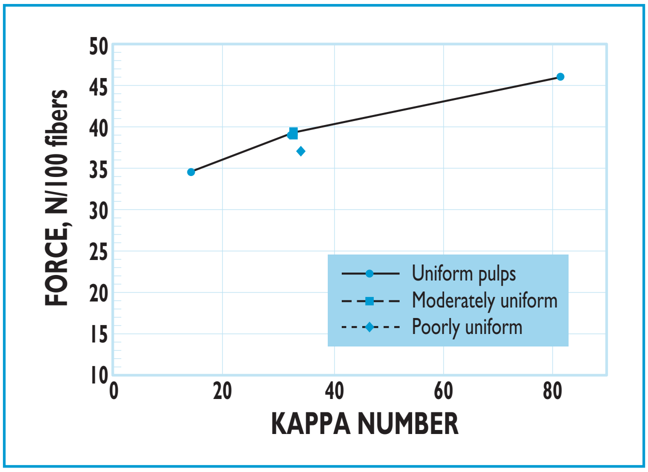
VI. Pulp viscosity results

RESULTS

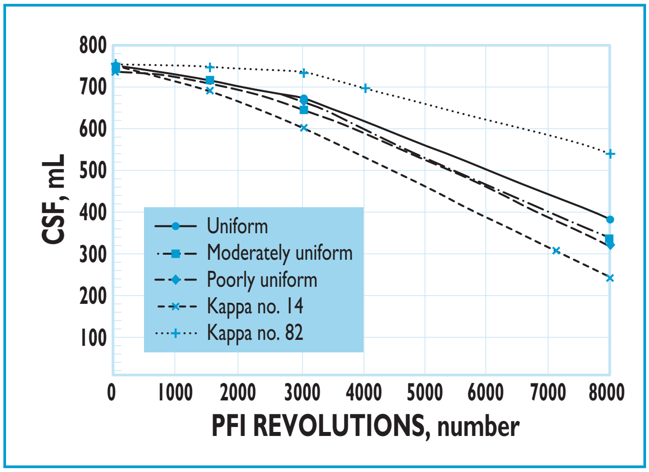
Table IV shows the kraft pulping data. The rejects were all very low due to the effective chip screening and mild pulping conditions. Even the kappa no. 82 pulp had low rejects. The pulp necessary to create the two mixtures was weighed and combined. The linear rule of mixtures provided a calculation of the weight percentage of each pulp necessary to achieve kappa no. 32 for the mixture. The calculated average kappa number value for the moderately uniform mixture was 33.1 but the actual value was 33.5. The calculated average kappa number for the poorly uniform pulp was 33.7, and the actual value was 33.5. Consequently, the pulp kappa numbers for these mixtures follow the linear rule of mixtures.

Table V shows the fiber morphology data. The kappa no. 82 fibers are longer, straighter, and coarser than the kappa no. 14 fibers. No fiber morphology differences exist between the uniform pulp and the two mixtures. Pulp viscosity measurement on the uniform, moderately uniform, and poorly uniform mixtures used TAPPI T230. **Table VI** shows the results. The control pulp had 36% higher viscosity than the poorly uniform mixture and 19% higher viscosity than the moderately uniform mixture.

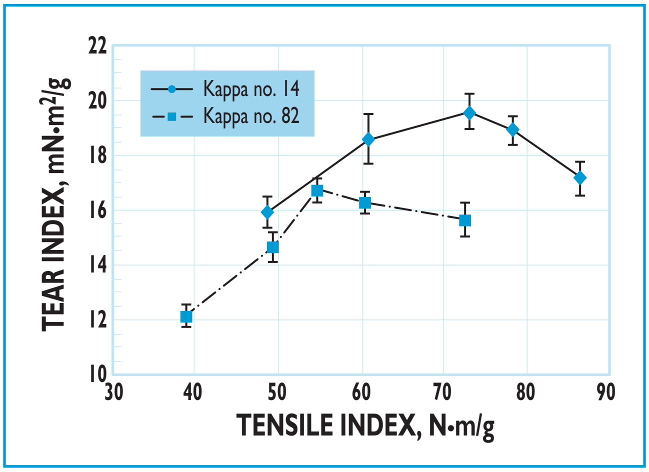
Table VII shows the wet zero-span tensile index data. The data represent the wet zero-span tensile index of the brownstock mixtures and the kappa nos. 14, 22, 44, and 82 unblended pulps. The error in the table is the 95% least significant difference.



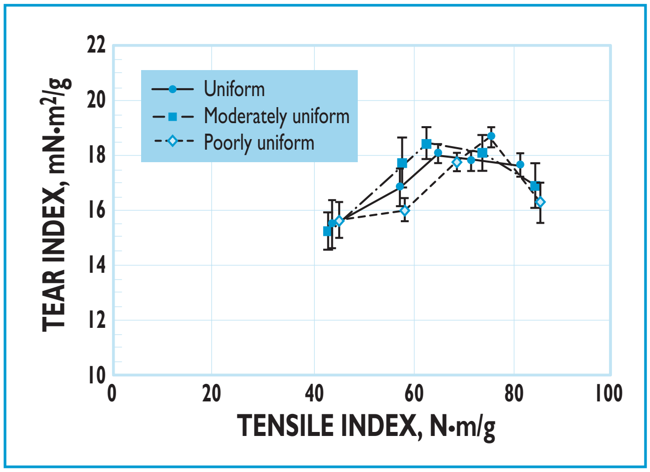
3. Comparison of wet zero-span tensile indices normalized using coarseness values



4. Refining response of mixtures and pulps with extreme kappa numbers



5. Tear vs. tensile index for kappa nos. 14 and 82 pulps



6. Tear vs. tensile index for the pulp mixtures

Sample	Wet Z-span tensile index, N·m/g	LSD
Control, kappa no. 32	148.90	3.86
Moderate mixture	145.68	5.86
Poor mixture	144.56	7.79
Kappa no. 14	143.73	5.21
Kappa no. 22	148.91	3.72
Kappa no. 44	150.16	4.41
Kappa no. 82	143.70	8.30

VII. Wet zero-span tensile index data for brownstock

The wet zero-span tensile data shows lower pulp strength for the kappa no. 14 and kappa no. 82 pulps, but the data are not statistically significant. A trend exists in the mixtures. When a pulp mixture contains a larger amount of higher and lower lignin content fibers, the brownstock strength is lower but not statistically significant. In addition, the reproducibility of the mechanical properties becomes poorer with increased kappa number variability. The kappa no. 82 and poorly uniform mixture have poorer reproducibility represented by the higher LSD.

The wet zero-span tensile index data does not show differences for the control pulp and the two mixtures. Apparently, an insufficient amount of low and high kappa pulp was present to affect the mixture. Even with viscosity differences, little strength difference existed for the moderately uniform, poorly uniform, and the control pulps.

Figure 3 shows the wet zero-span tensile data corrected for differences in coarseness by normalizing the strength. The differences in the normalized strength data of the mixtures compared with the control are insignificant. Consequently, the total intrinsic fiber strengths are similar. Even at a kappa no. 14, the fibers are not markedly degraded.

Figure 4 shows the freeness vs. number of revolutions for the mixtures and the control. The kappa no. 14 and kappa no. 82 pulps showed significant differences in their refining potential, but the control pulp vs. the mix-

Pulp	Final brightness
Control	85.3
Moderately uniform mixture	85.6
Poorly uniform mixture	85.9

VIII. Final brightness values for pulp mixtures after ECF bleaching

Pulp	Weight mean curl	WAFL, mm	Kink index	Kink angle	Coarseness, mg/100m
Uniform	0.096	1.02	1.02	39.5	25.9
Moderate	0.096	0.92	0.92	35.0	26.0
Poor	0.089	0.95	0.95	36.1	26.0

IX.ECF bleached misture and starting pulp fiber morphology data

Sample	Wet Z-span tensile index, N·m/g	LSD
Control	136.98	2.75
Moderately uniform	138.96	3.09
Poorly uniform	135.64	2.75

X. Wet zero-span tensile indices of ECF bleached pulps

tures did not show any differences in their refining responses.

Tear and tensile index were measured on a PFI refining curve. **Figure 5** shows the tear vs. tensile index for the kappa no. 14 pulp compared with the kappa no. 82 pulp. The error is the 95% LSD.

The kappa no. 82 pulp is weaker even with a longer fiber length (WAFL) because the high amount of lignin remaining in the fiber decreases the fiber bonding. Fibers from the kappa no. 82 pulp were also not as compressible as shown earlier by the high coarseness values of Table IV.

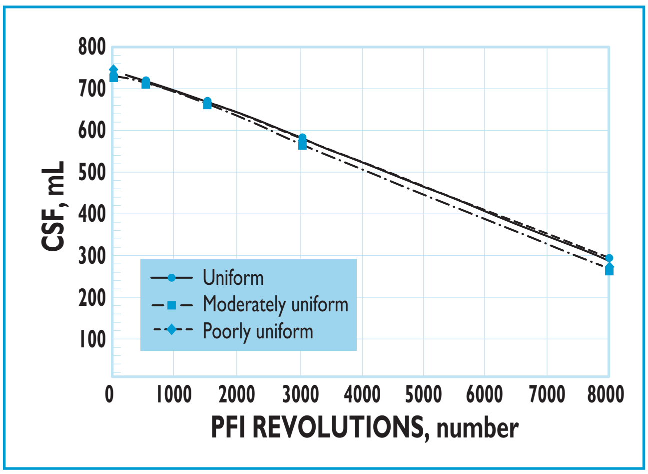
Figure 6 shows the tear vs. tensile relationship for the control pulp compared with the two mixtures. The error is the 95% LSD.

Correlating with the wet zero-span data, there is no statistical difference between the two mixtures and the control pulp. As mentioned earlier, all the pulps were inherently strong and remained undamaged in the mild pulping process. The poorly uniform pulp does develop strength more slowly. The peak in the tear vs. tensile curve develops later than the uniform and moderately uniform mixtures. As noted above, the poorly uniform pulp contained more kappa no. 82 pulp that had more lignin. The three mixtures did not have any significant differences in coarseness or fiber length.

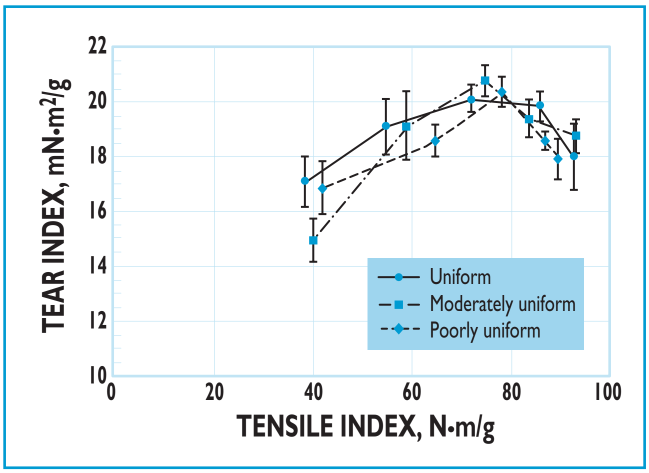
After ECF bleaching, only small differences existed between the pulps of different kappa number uniformity. **Table VIII** shows no differences in final brightness values. **Table IX** shows the fiber morphology values measured on the bleached pulps. No significant differences exist in fiber morphology for the bleached pulps. **Table X** shows the ECF wet zero-span tensile data. The error calculated is the 95% LSD. As expected from the previous brownstock wet zero-span tensile data, no statistical differences existed in zero-span tensile indices for the ECF bleached pulps.

Figure 7 shows no differences in refinability. The bleached stock refining response is not surprising since no refinability differences occurred in the brownstock results between the mixtures and the control pulp. **Figure 8** shows no strength differences between the mixtures and the control as shown by the tear vs. tensile index curves. The error is the 95% LSD. Even after bleaching with an ECF sequence, the fibers maintained the same strength properties shown by the brownstock results. The pulp strength was independent of uniformity.

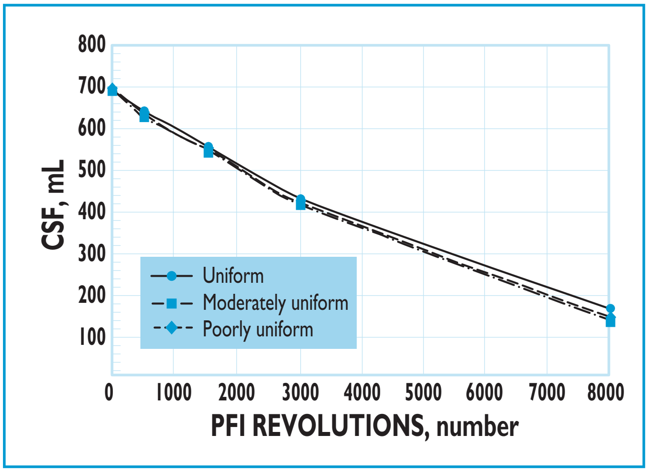
Table XI contains the final brightness values for the pulps after the TCF bleaching sequence. The moderately uniform mixture has higher brightness than the control and poorly uniform mixture. After application of the TCF bleaching sequence, the pulps did show some strength differences as **Table XII** indicates. The error is the 95% LSD.



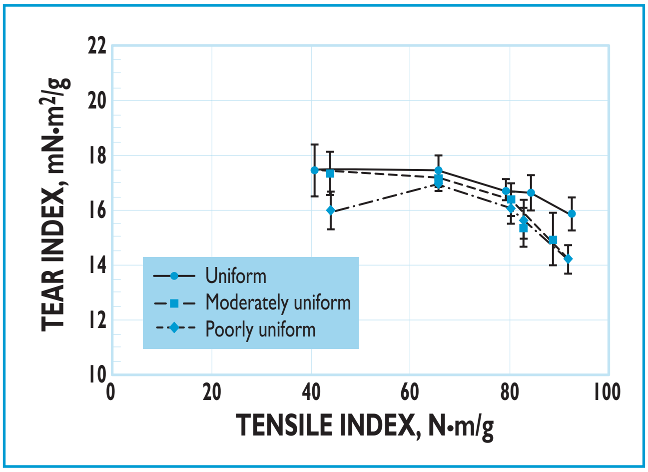
7. Refining response for ECF bleached pulp mixtures



8. Tear vs. tensile indices for ECF pulp mixtures



9. Refining response for TCF bleached pulp mixtures



10. TCF tear vs. tensile index PFI refining curves

Pulp	Final brightness
Control	81.6
Moderately uniform mixture	83.8
Poorly uniform mixture	80.6

XI. Final brightness values for pulp mixtures after TCF bleaching

Sample	Wet Z-span tensile index, N·m/g	LSD
Control	120.1	3.45
Moderately uniform	113.4	4.99
Poorly uniform	119.7	3.04

XII. Wet zero-span tensile indices of TCF bleached pulp

The moderately uniform pulp has a lower tensile index than the uniform pulp, but the result is not statistically significant. The poorly uniform and control pulps were similar. The moderately uniform mixture may have received a higher dose of ozone especially since the moderately uniform pulp had the highest brightness and the lowest zero-span tensile. Applying consistent ozone doses is more difficult because ozone is applied as a gas mixture.

Figure 9 shows that the refining potential for the pulps after TCF bleaching was similar to the ECF results. No refining potential difference existed between the pulps. **Figure 10** shows the tear vs. tensile index relationship for the TCF pulp. The error is the 95% LSD.

The control pulp was 8.4% stronger than the poorly uniform mixture at 40 tensile index and was 10.6% stronger at 90 tensile index. Figure 10 shows that the poorly uniform mixture has a lower tear and tensile index for the entire refining curve. At an 80 tensile index, the moderately and poorly uniform pulp strengths decline more rapidly than the control pulp. More work is necessary to confirm the response to the TCF bleaching.

CONCLUSIONS

This study compared two mixtures with varying kappa number distributions with a uniform control pulp having the same average kappa number. Bleachability and strength were measured. Previous workers did similar experiments, but the pulping conditions in this experiment created pulp with varying kappa numbers while minimizing fiber damage. Consequently, the chemical effect of lignin resulting from pulping to varying kappa numbers on pulp strength was measured. The results indicate that the kappa uniformity did not affect strength. This implies that lignin content alone may not reduce strength and decrease bleachability in nonuniform pulps. Under normal conditions, lignin content links strongly to other factors such as mechanical effects that weaken the fibers. Temperature, chemical concentration, blow temperature, washing, and many other factors within the pulp mill and bleach plants can contribute to damaging fibers. Curl, kink, twists, and dislocations can be due to the loss in pulp strengths *(8)*.

Even after bleaching, the pulps did not show any differences. This lack of strength loss is not surprising since previous work showed that laboratory pulps show little bleach strength loss. In a mill, pulp typically loses strength in the bleach plant and may have a strength delivery of only 75% of the original brownstock strength *(9)*.

The results of this study show no differences in brownstock strength or bleachability for the mixtures tested if the mechanical factors in a pulp are minimum. The lignin content alone does not have a negative impact on fiber performance over this range of kappa variability. Pulp uniformity is still an issue because the factors minimized in this work still exist in a mill to influence pulp quality. **TJ**

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