THE EFFECT OF MECHANICAL TREATMENT ON SOFTWOOD KRAFT PULP FIBERS

Pulp and fiber properties

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ABSTRACT

In this study the effects of mechanical treatment of kraft pulp fibers, at different temperatures, on pulp and pulp strength properties were investigated. The beating demand increased while the tear index and zero-span tensile strength of treated pulps decreased as the treatment temperature was increased from 100°C to 170°C. The carbohydrate compositions measured as monosaccharides after acid hydrolysis of the pulps were the same. The small differences in fiber deformation of the bleached pulps could not explain the severe strength losses at 170°C. The fracture analysis, together with the results of a fractionation study of treated pulps, indicated that single fiber strength was lost. The results also indicated that the fiber damage resulting from mechanical treatment at high temperature under alkaline cooking conditions led not to a reduction in interfiber bonding ability.

TIIVISTELMÄ

**MEKAANISEN KÄSITTELYN VAIKUTUS HAVUPUUSELLUKUITUIHIN
Massa- ja kuituominaisuudet**

Tutkimuksessa tarkasteltiin eri lämpötiloissa suoritetun mekaanisen käsittelyn vaikutuksia sulfaattisellukuituihin sekä kuituarkkien lujuusominaisuuksiin. Käsittelyn seurauksena todettiin jauhatustarpeen kasvavan ja repäisylujuuden ja zeron-span-vetolujuuden laskevan käsittelylämpötilan kasvaessa 100 °C:sta 170 °C:een. Kuitujen hiilihydraattikoostumus, joka analysoitiin happaman hydrolyysin jälkeen monosakkarideinä, todettiin samanlaiseksi. Pienet erot kuituvauriomittaustuloksissa eivät selittäneet suurta lujuusmenetystä mekaanisen käsittelyn tapahduttua 170°C:ssa. Vaurioleveysmittaukset ja fraktiointikokeet viittaavat siihen, että yksittäisen kuidun lujuus olisi alentunut ja ettei mekaaninen käsittely korkeassa lämpötilassa alkalisissa olosuhteissa johtanut kuitujen sitoutumiskyvyn alenemiseen.

INTRODUCTION

The unique attribute of softwood kraft pulp above that offered by any other type of commercial wood pulp is its physical strength. This has resulted in many studies aimed at improve strength properties /1, 2, 3, 4/. All these research efforts have been appropriate because strength is regarded as the most important property of softwood kraft pulp. The driving force behind these studies has been the saving potential of kraft pulp and the improved properties of the paper produced. The significance to the paper maker is that the use of a stronger pulp means less softwood kraft pulp is required which will result in better optical and surface properties of the paper.

About four decades ago, during the development of the modern Kamyr continuous digester, pulp strength loss from kraft continuous digesters was first investigated. It was found that under conditions typical of blow line flow, mechanical action on cooked softwood fibers resulted in localized damage to fiber cell walls /1/. Annergren et al. /2/ found several years later, using a special sampling device to study pulp strength before and after discharge, that discharge should be done at 100°C rather than at 145°C to avoid fiber damage.

A number of studies over recent years have shown that fiber strength decreases along the fiber line starting from the digester discharge /5, 6, 7, 8, 9/. Fiber strength decreases by 15-20% in the fiber line according to Tikka et al. /9/ and most of it has disappeared before oxygen delignification. There are, however, opposing views which state that the fiber processing line after cooking is not the cause of fiber damage /10/.

Strength also tends to be much lower for a pulp from an industrial digester than from a laboratory cook or hanging basket experiment, although the pulping chemistry is the same.

Traditionally the tensile and tear strengths have been explained with various fiber network models. The strength of a fiber network has been described in many ways in the literature /11/. The microscopic parameters such as bond strength and fiber strength are usually not measurable for the network. These parameters are complicated because they are sensitive to sheet structure and the paper making process. Fracture mechanics have also been used to explain paper strength, the advantage being that there are none of the problems associated with defining the weakest point of the network. These studies have shown that the damage width can be used to evaluate fiber properties such as the effective fiber length and the strength of the fibers in the paper.

Earlier studies indicated that mixing of bleached or unbleached kraft pulp fibers at medium consistency resulted in increased curl and created dislocations on the fibers. Pulp fiber deformations have also been used to give an indication of fiber strength /12-15/.

The objective of this study was to investigate how fiber physics and fiber strength were affected if the fibers were mechanically damaged. The mixing treatment was chosen because it would simulate, in the most simple and effective way, the mixing, pumping and pipe line conditions in a kraft pulp mill fiber line

Experimental

Apparatus

The experimental work was carried out in two different kind of digesters: in a forced circulation digester (volume 30 litres) and in a laboratory batch digester, which was equipped with a mixing propeller (Fig.1). The axel beam of the mixing device was fitted through the lid of the digester. The batch digester (volume 40 litres) was heated with hot water, which was pumped to circulate in the water jacket around the digester. The water jacket also made rapid temperature changes possible. The temperature inside the batch digester was measured from the end of the mixing plate to ensure that exact temperature of the contents was obtained.

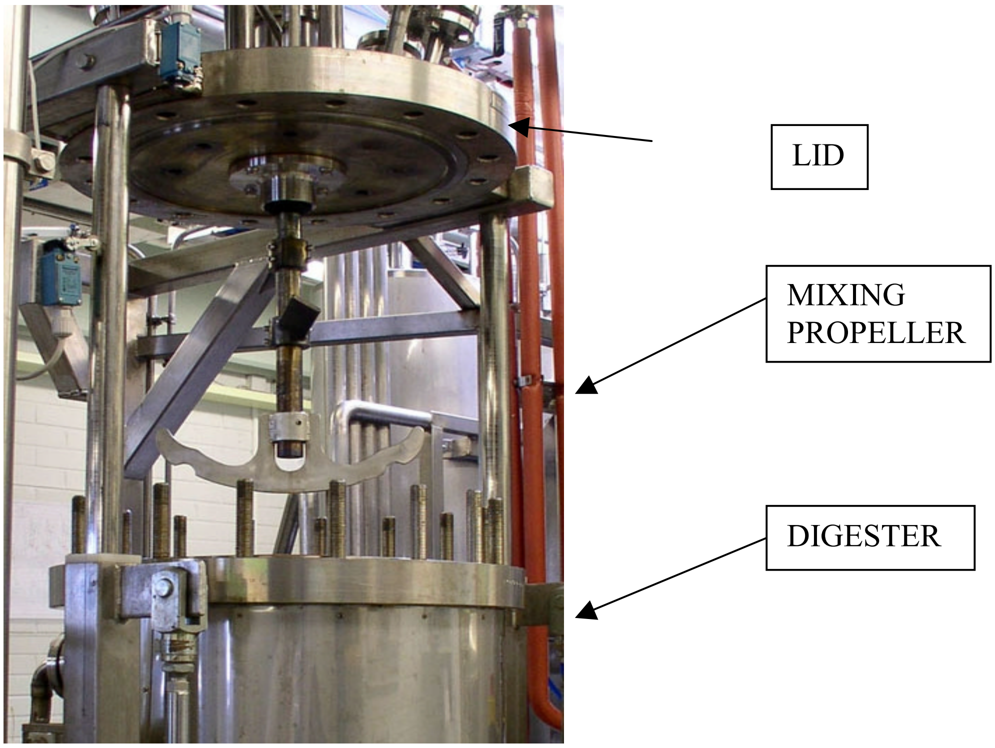

Fig. 1. The laboratory batch digester with mixing device.

Raw Material

The wood raw material used in this study was industrial softwood. The chip mixture consisted of 65% pine (Pinus sylvestris) and 35% spruce (Picea abies). About 50% of the raw material was sawmill chips. Chips were screened using a Williams screening test. The chips had an average thickness of 4.8 mm; 88.3% of the chip mass fell in the 2-8 mm range, and 92.7% was retained by the 7 mm holes.

Pulping conditions

Conventional laboratory kraft cooks of the chips were carried out. Cooking was performed in a 30 litres forced-circulation laboratory digester (designated REF). Into the digester were placed 5000g (dry weight) chips and the liquid to wood ratio was 4. The alkali charge was 3.545 mol/kg NaOH and the charge of Na_2S was 0.955 mol/kg. The temperature was raised from 50^{o}C to 80^{o}C in 15 minutes and from 80^{o}C to 170^{o}C in 90 minutes. At the end of the cook the H-factor was 1600 and the residual alkali as effective alkali was 5,41g/l. The kappa number target was 30. The cooked pulp was washed over night with ion-exchanged water and screened with vibrating plate screen, first stage slot 2mm and then the second stage slot 0.35 mm. The pulp was centrifugated and homogenized.

The pulping with mixing and temperature changes was performed in a laboratory batch digester, which was equipped with a mixing propeller. The cooking parameters used in this study were as follows: The temperature was raised from 50^{o}C to 170^{o}C in 95 minutes and the cooking temperature was kept for 110 minutes. The alkali charge was 3.545 mol/kg NaOH and the charge of Na_2S was 0.955 mol/kg and the liquor to wood ratio was 4 and the kappa number target was 30. All of the pulps were stirred at 30 rpm in order to ensure even alkali and temperature distribution during cooking. The pulp, designated NOMIX, had only this 30rpm stirring during the whole cooking. The H-factor for NOMIX at the end of the cook was 2100. Mixing at 170, 130 and 100^{o}C (designated MIX170, MIX130 and MIX100) consisted of additional mixing, which started 15 minutes before the end of the cook. The mixing was carried out at a speed of 350 rpm. The H-factor at the end of the MIX170 cook was 2240. For the cooks mixed at 130^{o}C and 100^{o}C the temperature was lowered to the target value with the water jacket before mixing for 15 min. The H-factor for the pulp MIX130 was 2190 and for the pulp MIX100 2100. The total amount of energy fed into the MIX170, MIX130 and MIX100 cooks during mixing was approximately 20 kWh/t.

Pulps were bleached to a brightness of 88% with a DEDED bleaching sequence. The sample preparation of the pulps is shown in Table 1.

Table 1. The sample preparation of the pulps used in the study. Typical bleaching conditions to achieve a brightness of 88%.

Sample	**Digester**	**Mixing**
REF	Forced-circulation digester	No mixing at all
NOMIX	Digester with mixing propeller	30 rpm stirring during cooking
MIX170	Digester with mixing propeller	30 rpm stirring during cooking and mixing at 350 rpm at 170°C started 15 minutes before end of cook
MIX130 MIX100	Digester with mixing propeller	30 rpm stirring during cooking and mixing at 350 rpm at 130°C and 100°C 15 minutes after lowering to target temp.

Bleaching conditions

Stage	Charge, % ClO_2	 NaOH	Temperature, °C	Consistency, %	Time, min	Washing
Do	6.36	-	50	3	60	Ion-exchanged water: 2x10x amount of pulp, between stages.
E1	-	2.86	60	10	60	
D1	2.52	-	70	10	150	
E2	-	0.80	70	10	60	
D2	1.1	-	70	10	150	

The sheets for testing were made according to ISO 5269-1. Kappa number was determined according to SCAN-C 1:77 and viscosities according to SCAN-CM 15:88. Fiber length and fiber coarseness were measured using a Kajaani FS-200. Beating was performed using a PFI beater according to SCAN-C 24:67 to 500, 1000, 1500 and 2000 revolutions. Tensile strength was measured according to standard SCAN-P 38:80, tear index was measured according to standard SCAN-P 11:73 and zero-span tensile index (from rewetted sheets, Pulmac) according to ISO 15361.

Microscopic damage analysis was used to measure the spatial extent of microscopic damage along the crack line of the paper or pulp sheets. The parameters were pull-out width, damage width and tearing work index. The pull-out width indicates the length of the fiber ends that can be extracted from the sheet along a fracture line. The damage width measures the area in which fiber debonding takes place. A wide damage area means that a lot of fracture energy is consumed in breaking interfiber bonds. A narrow damage area compared to fiber length in turn means that fibers break during the fracture of the sheet. Tearing work index is an indicator of the amount of work required to tear the sample using an in-plane tear test /16, 17/.

The fractionation of mixed and unmixed pulps was carried out using the Bauer McNett device according to SCAN M-6. The Bauer McNett + 14 fractionated and unfractionated pulps were beaten in the PFI-beater.

In order to study the monosaccharide composition, the pulps were first hydrolyzed with sulphuric acid and the solutions analyzed by liquid chromatography, according to Hausalo /18/.

Fiber damage of the bleached and unbleached pulps was measured. The curl was measured with a Pulp Expert fiber analyser and by light microscopy. Light microscopy measurements of curl and kink were carried out according to Page et. al. /19/ and Jordan et. al. /20/. Microscopic curl and kink measurements were carried out using 300 fibers. The degree of dislocation was measured according to Pihlava /8/. The bleached pulps were beaten with a PFI beater to a tensile index of approximately 70 N•m/g. Fiber damage analysis was carried out also for the bleached and beaten pulps.

RESULTS AND DISCUSSION

Pulp properties

In Table 2 the properties of the MIX pulps, mixed at temperatures of 170°C, 130°C, 100 °C (350 rpm for 15 min.), the NOMIX pulps (only stirred during cooking at 30 rpm.) and the unmixed pulp (REF) are shown.

Table 2. Pulp properties of mechanically treated MIX pulps (at temperatures of 170°C,130°C and 100 °C), NOMIX pulp and REF pulp.

Pulp	Analysis	MIX170	MIX130	MIX100	NOMIX	REF
Unbleached	Kappa	27.0	33.2	31.9	33.4	31.8
Unbleached	Viscosity, ml/g	1250	1350	1350	1360	1320
Unbleached	Yield, %	47.9	47.3	47.9	48.9	48.5
Bleached	L.w.av.* fiber length	2.26	2.24	2.30	2.33	2.25
Bleached	Coarseness, mg/m	0.246	0.237	0.246	0.229	0.227
Bleached	Viscosity, ml/g	1090	1160	1160	1210	1180

*Length weighted average

Table 2 shows that the lowest kappa number was obtained when mixing was performed at 170 °C at the end of the cook which also had the highest H-factor; the kappa numbers of the other pulps were at similar levels. A more even temperature distribution as a result of mixing at the end of the cook might explain this.
The cooking yields of the mixed pulps at temperatures of 170°C, 130°C and 100 °C, were lower than those of the NOMIX and REF pulps. The lowest viscosity was obtained for the MIX170 pulp. However, when viscosities were calculated to the same kappa number level there were no differences between the pulps. The fiber length of the bleached mixed pulp was at the same level as that of the unmixed pulp, in spite of mixing. This indicated that the fibers were not cut during mixing.

Strength properties

The pulps were bleached using a DEDED sequence to a brightness of 88% and beaten in a PFI beater. The tear index, Scott Bond, zero-span index measured from rewetted sheets, light scattering and PFI revolutions at tensile indices of 50 N•m/g and 70N•m/g measured for mixed MIX, NOMIX and unmixed REF pulps are shown in Table 3.

Table 3. PFI revolutions, tear index, Scott Bond, zero-span index and light scattering tensile indices of 50 N•m/g (T50) and 70•Nm/g (T70) measured for mixed and unmixed pulps.

Analysis	MIX170	MIX130	MIX100	NOMIX	REF
PFI revs. to T50	659	398	352	425	424
PFI revs to T70	1922	1343	1042	1093	1204
Tear ind, mN•m2/g @T50	17.8	23.0	23.2	26	28.9
Tear ind, mN•m2/g @T70	11.7	17.9	18.2	19.7	22.6
Scott Bond @T50	222	211	189	-	232
Scott Bond @T70	307	275	247	271	290
Light Scatt. coeff., m2/kg @T50	22.0	23.0	22.6	-	-
Light Scatt. coeff., m2/kg @T70	19.2	19.6	19.2	19.8	18.7
Bulk, dm^3/kg @T50	1.48	1.56	1.54	-	-
Bulk, dm^3/kg @T70	1.44	1.45	1.47	1.46	1.46
Zero-span (wet), N•m/g @T50	119.7	122.8	130.5	132.5	130.7
Zero-span (wet), N•m/g @T70	123.8	132.4	131.6	142.6	141.1

The strength indices measured for mixed and unmixed pulps, shown in Table 3, indicate that there was a severe strength loss because of mixing. At a tensile index of 70 N•m/g (T70) the zero-span (wet) index of the MIX170 pulp was 13% lower than that of the REF pulp and the tear index was 50% lower.

The Scott bond values measured for the bleached pulps T70, shown in Table 3, show large variations. The higher Scott Bond of the MIX170 pulp compared to the REF and NOMIX pulps, however, indicated that this pulp had a higher bonding ability. This suggests that the loss in strength could not be explained by poorer fiber bonding.

As well as affecting strength properties, mixing also affected the beatability of the pulps as indicated in Table 3. There was almost a doubling of the number of PFI revolutions required to achieve a tensile index of 70 N•m/g at 170oC. In Figure 1 tear index is shown as a function of tensile index for the pulps studied.

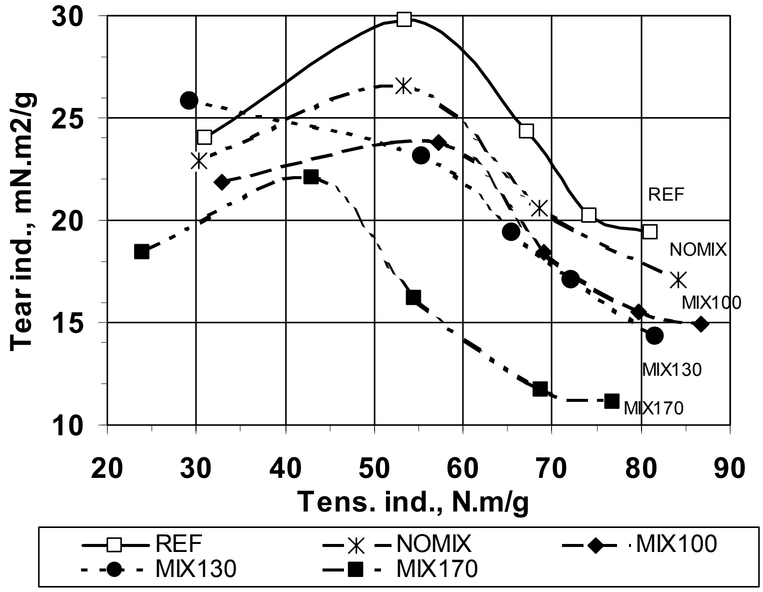

Figure 2. The effect of mechanical treatment on tear index as a function of tensile index of the DEDED-bleached pulps. Pulp was mixed (MIX) in the end-of-cook liquor at 100,130 and 170°C. REF= unmixed pulp. NOMIX= stirred during cooking at 30 rpm.

As Figure 2 shows the tear strength of the DEDED-bleached pulps decreased when they had been subjected to mechanical stress at the end of the cook. A higher temperature during the mechanical treatment led to increased strength loss. When the treatment temperature was 170°C, the tear index at a tensile index of 70 N•m/g decreased dramatically (by approximately 45% compared to the reference). Even slight stirring during cooking reduced the tear index of the NOMIX pulp by 10% at a tensile index of 70 N•m/g compared to the REF pulp. In Figure 3 the zero-span tensile index of rewetted sheets is shown as a function of tensile index.

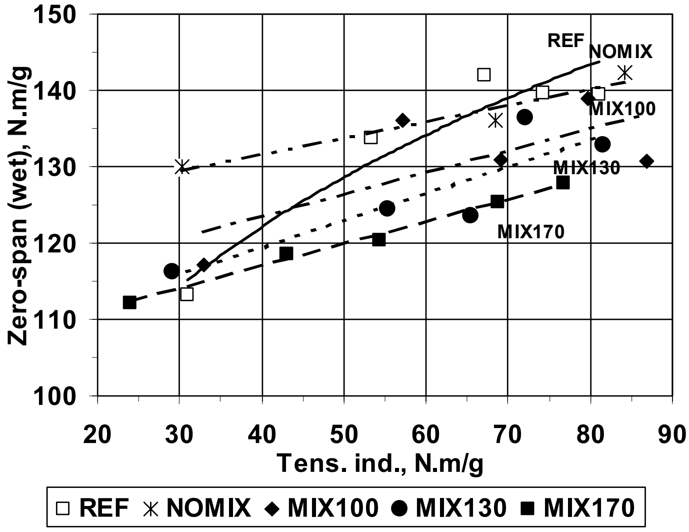

Figure 3. The effect of mechanical treatment on zero-span tensile index (wet) as a function of tensile index of the DEDED-bleached pulps. Pulp was mixed (MIX) in the end-of-cook liquor at 100,130 and 170°C. REF= unmixed pulp. NOMIX= stirred during cooking at 30 rpm.

Figure 3 shows that the zero-span index as a function of tensile index decreased when the mixing temperature was increased, although this phenomenon was not as clear as with tear index. The reason for a decreased zero-span values, according to Gurnagul and Page /21/, might be the weakening of the sheets by wetting, which is dependent on the chemical and mechanical treatment that the pulp has received. Gurnagul and Page hypothesize also that the mechanical treatment might have weakened the lignin-hemicellulose matrix (cause chemical differences) allowing the fibrils to slide over one other, thus reducing wet fiber strength. Another possible explanation could be that the zero-span should be measured from well beaten straight fibers otherwise the fiber curl and fiber defects decrease the zero-span values, Seth /22/. In this case the curl values measured (Table 6) from the pulps at different beating degrees shows that at certain tensile index MIX170 pulp had lower curl.

In order to determine the reasons for the dramatic strength loss, the extreme pulps, MIX170 and NOMIX, were selected for further investigation. The pulps were cooked in the same digester and the only difference in cooking conditions between them was the 15 min mixing at 170°C at the end of the cook. The tear index difference at a tensile index of 70 N•m/g was 8 units. Although there were large differences in tear and zero-span indices between the NOMIX and MIX pulps, there were also many similarities between them, particularly with respect to fiber length, bulk, and viscosity.

Carbohydrates remained unchanged

It is a known fact that the carbohydrate composition of pulp affects the fiber strength properties /23, 24, 25/, although there have also been different views /26/. It is suggested, for example, that the presence of hemicellulose is important for maintaining a straight and strong fiber /24/. It follows, therefore, that variations in carbohydrate composition should provide an indication of differences in strength properties. The concentrations and types of monosaccaride species detected by liquid chromatography following acid hydrolysis of the bleached pulps are shown in Table 4.

Table 4. The carbohydrate composition of the unbleached MIX and the NOMIX pulps, detected as monosaccharides after acid hydrolysis.

PULP	Monosaccharides after acid hydrolysis, %				
	Arabinose	Galactose	Glucose	Xylose	Mannose
NOMIX	0.7	+	84.9	8.1	6.3
MIX	0.7	0.3	84.9	7.9	6.2

Carbohydrate composition presented as monosaccharides after acid hydrolysis of bleached NOMIX and MIX170 pulps did not indicate any difference between the pulps. It may be presumed, therefore, that the strength loss was not due to measurable changes in carbohydrate composition.

Fiber damage analysis

In Table 5, the results from the fiber damage measurements performed on the unbleached MIX170 and NOMIX pulps are shown.

Table 5. Fiber damage measured for unbleached MIX and NOMIX pulps using a light microscope and PulpExpert.

	NOMIX	MIX
Light microscope		
Degree of dislocation	2.20	1.71
Kinks, number of kinks /mm	0.47	0.40
Curl index, %	0.34	0.39
Pulp Expert		
Curl, %	12.3	13.7

Table 5 shows that the degree of dislocation and the number of kinks measured with the light microscope were lower for the unbleached MIX170 pulp than for the NOMIX pulp. Both light microscope measurements and the Pulp Expert indicated that the MIX170 pulp had more curl than the NOMIX pulp.

Light microscopy was also used to determine fiber damage to the bleached pulps after PFI beating. The beating required to achieve a tensile index of 70 N•m/g was approximately 1000 revolutions for the NOMIX pulp and approximately 2000 revolutions for the MIX170 pulp. The results are shown in Table 6.

Table 6. Fiber damage measured for bleached NOMIX and MIX pulp. DEDED bleached. 0= no beating, 1000 and 2000 = PFI beating to 1000 and 2000 revolutions.Beating levels of 1000 and 2000 revolutions gave the same tensile index values of 70 N.m/g.

	NOMIX 0	NOMIX 1000	MIX 0	MIX 1000	MIX 2000
Degree of dislocation	2.50	2.60	2.50	2.60	2.90
Curl index, %	0.40	0.30	0.56	0.35	0.17
Fiber length, l.w. average, mm	2.59	2.88	2.74	2.78	2.65
Kinks, number of kinks /mm	0.28	0.20	0.31	0.25	0.07
Tensile index, N·m/g	30.3	68.5	23.9	54.4	68.8

Table 6 shows that the curl index and the number of kinks of the bleached unbeaten MIX170 pulp were slightly higher compared to unbeaten NOMIX pulp. The tensile index of the unbeaten NOMIX pulp was higher compared to the unbeaten MIX170 pulp. It is a known fact that fiber curl influences tensile index and zero-span tensile index so that they decrease with increasing fiber curl /22/. When the curl index and the number of kinks of the MIX170 and the NOMIX pulps are compared at the same tensile index, it can be seen, that the curl of the NOMIX pulps was almost double and the number of kinks was more than double compared to the MIX170 pulp. The amount of PFI revolutions was double to reach tensile index 70 N•m/g for MIX170 compared to the NOMIX pulp. This indicates that the curl and the kinks is not the only reason for lower tensile and lower zero-span values in this study. It is difficult to find a clear correlation between fiber damage, tear index and zero-span index of the NOMIX and MIX170 pulps. This is because there is a reduction in both curl and in the number of kinks when the pulp is beaten /15/, i.e. fiber damage is thus reversible. The results also suggest, that these reversible changes (ie. curls, kinks and wall dislocations) indicate only that the fibers have been exposed to mechanical energy; they are not indicators of the severeness of the treatment.

Microscopic damage analysis and fractionation

The NOMIX and MIX170 DEDED-bleached pulp sheets were tested using in-plain tear testing and damage analysis techniques (Figure 4) developed by Kettunen and Niskanen /16, 17/. The pulps were also fractionated and the strength properties of the long fiber fractions were compared to those of the bulk pulp.

Figure 4 shows the damage width as a function of pull-out width for the DEDED-bleached MIX170 and NOMIX pulps.

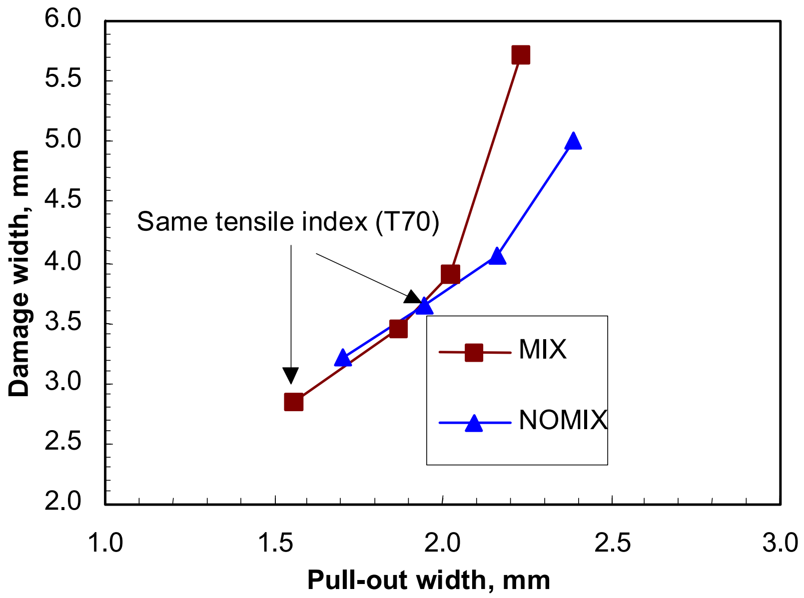

Figure 4. Damage width as a function of pull-out width for DEDED-bleached NOMIX and MIX (at 170°C) pulps.

At the same tensile index the damage width and pull-out width were much lower for the MIX170 pulp than for the NOMIX pulp (Figure 4). This indicates that the single fiber strength in the sheet made of mixed fibers was significantly lower than that of the unmixed fibers. In Figure 5 the tearing work index is shown as a function of damage width for the DEDED-bleached NOMIX and MIX170 pulps.

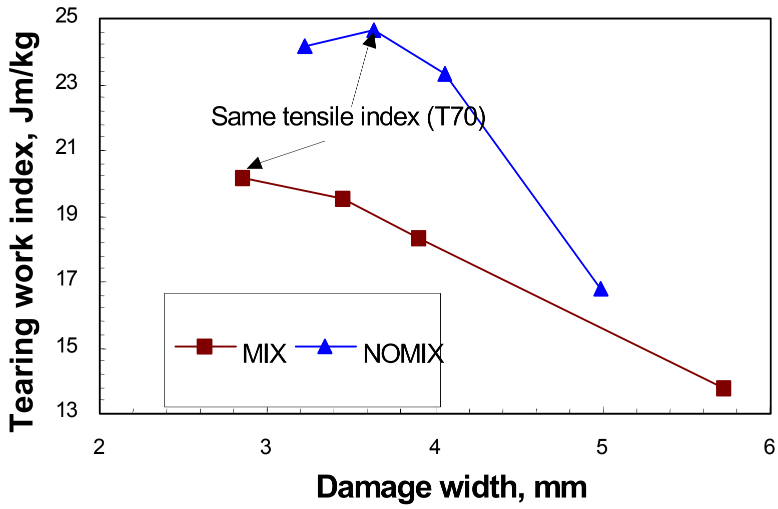

Figure 5. Tearing work index as a function of damage width for DEDED-bleached NOMIX and MIX pulps.

Figure 5 shows that the damage width of the MIX170 pulp was approximately 1mm smaller at the same tensile index. Less tearing work was required to break the sample made from MIX170 fibers than that made of NOMIX fibers if samples were compared at the same tensile index. This also indicates that the strength of a single fiber was lower for the MIX170 than for the NOMIX pulp. The reduced damage width at the same tensile index confirms this.

It may be concluded from the results presented in Figures 4 and 5 that the mixing treatment reduced the single fiber strength but not the bonding ability (i.e. the interfiber bonds).

Figure 6 shows the tear index as a function of tensile index for the DEDED-bleached Bauer McNett + 14 fractionated and unfractionated pulps. Fractionation was carried out for both NOMIX and MIX170 pulps.

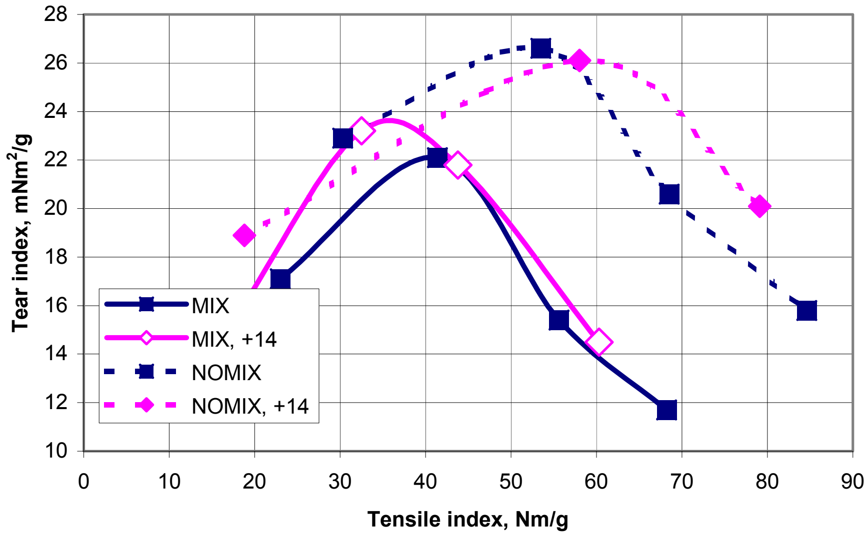

Figure 6. Tear index as a function of tensile index for NOMIX and MIX pulps and Bauer McNett +14 fractions (PFI beating).

The long fiber fraction (+14 fraction) of the NOMIX pulp (Figure 6) had a higher tear index at the same tensile index compared to the bulk pulp. The long fiber fraction of the MIX170 pulp, however, had the same tear index as the corresponding bulk pulp. This indicates that even though the longer fibers in the +14 fraction (length weighted average fiber length approximately 3.3 mm for the +14 fraction) should have given a higher tear index, this did not compensate for the lost single fiber strength. This confirms the results from the microscopic damage analysis that the loss in strength origins from the loss of single fiber strength rather than fiber-fiber bonding ability.

CONCLUSIONS

This study showed that even low mechanical energy input damages kraft fibers under kraft cooking conditions. The strength difference between the unstirred reference pulp (REF) and the NOMIX pulp (stirred during cooking using only 30 rpm), measured as tear index at a tensile index of 70 N•m/g after DEDED bleaching and PFI refining, was 15 %. This study also showed that a higher energy input (i.e. mixing at 350 rpm for 15min) after cooking resulted in a higher loss. Depending on the mixing temperature, the maximum reduction in tear index of the MIX pulps was 45% at 170°C compared to the NOMIX pulp. Mechanical treatment, which in this case was mixing (ie. application of pressing and shear forces) at high temperature and high alkali charge, caused a decrease in the pulp strength of the fully bleached pulp. The main results were:

- There were no differences in yield and viscosity, so the reduction in strength properties could not be explained by cellulose degradation.
- Carbohydrate composition measured as monosaccharides after acid hydrolysis of NOMIX and MIX pulps did not indicate any difference between the pulps.

- The curl index for the unbeaten brown pulp was slightly higher for the mixed pulps than for the unmixed pulp.
- More than twice the number of revolutions were required to achieve the same tensile index (T50 and T70) of the bleached MIX pulp compared to the NOMIX pulp.
- At the same tensile index the bleached mixed pulp had lower damage width and in-plane tear strength.
- The long fiber fraction (BMcN +14) of the unmixed pulp had a higher tear index at the same tensile index compared to the corresponding bulk pulp, while the tear index of the long fiber fraction of the mixed pulp was the same as that of the whole pulp.
- There were small differences in the conventional fiber damage measurements, but the differences were not of great enough magnitude to result in a 45 % reduction in tear strength at a tensile index of 70 N•m/g.

The results of this study showed that fiber damage, which is a result of mechanical treatment at high temperature under alkaline kraft cooking conditions, led to a decrease in single fiber strength rather than a decrease in interfiber bonding ability.

Based on these studies new methods should be developed for investigating and understanding the nature of fiber damage and for finding ways to avoid it.

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