Preferred citation: O. Joutsimo, R. Wathén and L. Robertsén. Role of fiber deformations and damage from fiber strength to end user. In **Advances in Paper Science and Technology**, *Trans. of the XIIIth Fund. Res. Symp. Cambridge, 2005*, (S.J. I'Anson, ed.), pp 591–611, FRC, Manchester, 2018. DOI: 10.15376/frc.2005.1.591.

ROLE OF FIBER DEFORMATIONS AND DAMAGE FROM FIBER STRENGTH TO END USER

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ABSTRACT

Fiber deformations and damage have a considerable influence on both fiber strength and network properties. Through their influence on the fiber network, they can also affect the way paper behaves during converting. Another aspect is their influence on end-use properties, again via their effect on the fiber network.

Separating the effects of fiber deformations and damage is often difficult. We prepared pulps in the laboratory and subjected them to different treatments that change the two relatively independently in a controlled manner. We found that wet/dry zero-span fiber strength is not dependent on the deformation method or on the extent of the deformations. Neither pulp sheet density nor Scott bond bonding was greatly affected by the type or method of deformation. In the case of deformed pulps, the pulp sheet tensile properties were dependent on the extent of fiber deformation via fiber segment activation. The pulp that was damaged instead of deformed had fiber deformations to about the same extent as the deformed pulp but lower single fiber strength measured with wet/dry zero-span. It also had lower bonding ability and sheet density. The tear index for the unbleached damaged pulp was 20–25% higher than that of the reference pulps. Fiber deformations (curl and kinks) affect fiber network properties via

the lack of fiber segment activation. However, they do not significantly influence fiber shrinkage potential (WRV) or fiber strength.

INTRODUCTION

In nature, fiber deformations (defined as changes in the three-dimensional forms of fibers, e.g. fiber curl and kinks) can arise in a tree as a result of growth stresses. On the other hand, they can be induced in numerous ways in the pulpmaking process. Chipping, fiberization and medium-consistency unit operations are examples of the potential sources [1, 2]. Fiber deformation is usually associated with fiber damage although, as this study will show, deformation and damage are two different phenomena. Fiber deformation can be both desirable and undesirable, while fiber damage is considered undesirable and should be avoided wherever possible. Fiber deformations influence the properties of a fiber network [3] in many ways. In particular, they affect the tensile strength and the bonding ability of fibers in a network. Most fiber deformations vanish during pulp beating, and the strength properties return to those of the undeformed pulp [10, 12, 13]. The physical properties of the fiber wall have been reported to affect the development of fiber deformations. For example, medium-consistency fluidization induces more curl and microcompressions in thick-walled fibers than in thin-walled fibers [14].

According to Page [4], a sheet formed from curly fibers will have a low tensile index but may have high tear strength. This has been explained by the uneven distribution of stress along the length of a curled fiber in a fracture zone [5]. Curly fibers also tend to form sheets having a lower elastic modulus but higher stretch than sheets made from straight fibers [6].

Fiber kink is by definition calculated as part of fiber curl, but it has been reported to affect paper properties somewhat differently. For example, kinks have been reported to affect the wet strength of the pulp. The more kinked the fibers are, the higher the wet rupture energy. It has been suggested that chlorine-caustic and chlorine dioxide bleaching cause kinks present in the unbleached fibers to be set into position. Fiber kinking is unaffected by pulp drying stresses [11].

Fiber dislocations are defined as parts of the cell wall where the alignment of the microfibrils is locally disturbed [4]. A fiber with no dislocations is extremely stiff. Even a small number of dislocations can significantly reduce bending stiffness. Some delamination occurs in the dislocated regions, which at least partly explains the decrease in bending stiffness. As a fiber containing dislocations bends, it forms a polygon rather than a continuous curve [7, 8]. Like fiber curl, dislocations reduce the elastic modulus of the sheet [6]. Dislocations can become weak sites in the fibers, reducing the strength of the individual fibers and thus leading to a decrease in average fiber length [7, 8, 9]. This adversely affects certain pulp strength properties such as folding endurance and burst strength [8]. It has also been suggested that an increase in the number of dislocations increases the tear strength and stretch while decreasing bonding strength through creation of discontinuities that act as points of bond failure in stressed fiber networks [10].

The definition of fiber damage is not as clear as that of fiber deformation. Fiber damage can be a result of chemical degradation during pulping, but it may also arise from mechanical treatment. Fiber damage is usually seen as a reduction in strength of the dry or wet fiber network. The effect of fiber damage is difficult to determine, since several other factors also affect fiber network properties. According to Mohlin [15], reversible deformations can be removed by PFI beating while irreversible damage cannot. Mohlin [15] also suggested that irreversible damage could be defined as the difference in zero-span tensile index between straight undamaged and damaged fibers.

The objective of this study was to examine some of the effects of fiber deformations and fiber damage on fiber and fiber network strength properties. In addition, we connect these properties to paper web runnability and paper product end use.

EXPERIMENTAL

The wood raw material used in this study was Norway spruce (*Picea abies*). The cooking experiments were performed in two different types of digester. The undamaged and undeformed pulps were made in a 30 l forced-circulation laboratory digester whereas the damaged pulps were cooked in a laboratory digester equipped with a mixer. The mixing treatment was chosen because it creates both fiber deformations and damage. The authors of this study have shown that mixing treatment at high temperatures (170°C and 130°C) results in both fiber damage and fiber deformation [16]. The mixed pulp in this study is referred to as damaged. Figure 1 and Table 1 summarize the raw material, treatments and designations used in this study. Pulp deformation was performed in a homogenization device (Hobart kitchen type).

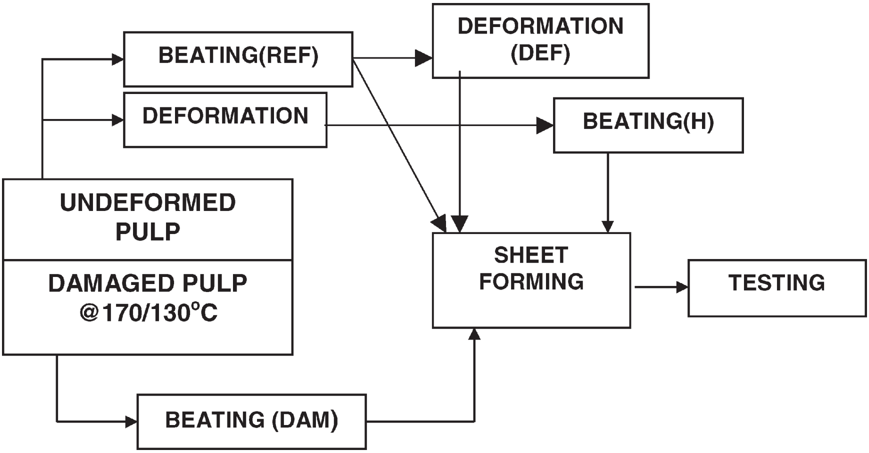

Figure 1 The raw materials and treatments used in this study. REF= beating in PFI, DAM= damaging + beating, DEF= beating + deformation, H=deformation + beating. The DAM130, DEF and REF pulps were bleached using the sequence DED (referred to as DAM130-bl, DEF-bl and REF-bl in the text).

Table 1 Designation and treatment procedure for the pulp samples.

Sample name	Pulp type	Treatment procedure
REF	Undeformed	Beating 2000 PFI revs
DEF	Undeformed	Beating 2000 PFI revs→ Deformation
H	Undeformed	Deformation→ Beating 2000 PFI revs
DAM170	Damaged @170°C	Beating 2000 PFI revs
REF-bl	Undeformed	Bleaching→Beating 3000 PFI revs
DEF-bl	Undeformed	Bleaching→Beating 3000 PFI revs→Deformation
DAM130-bl	Damaged @130°C	Bleaching→Beating 3000 PFI revs

Cooking conditions for undamaged pulps

The chips were subjected to conventional laboratory kraft cooking in a 30-liter forced-circulation laboratory digester (designated REF). The weight of chips was 5000 g (dry) and the liquid-to-wood ratio was 4. The effective alkali charge was 4.5 mol NaOH/kg dry wood. The sulfidity used in the cook was 35%. The temperature was raised from 50°C to 80°C in 15 minutes and from 80°C to 170°C in 90 minutes. At the end of the cook the H-factor was 1600 and the residual alkali (as effective alkali) was 5.41 g/l. The cooked pulp was washed overnight with ion-exchanged water and passed through a vibrating plate screen with a 2 mm first stage slot and a 0.35 mm second stage slot.

Damaging treatment conditions

The pulping with mixing (damaging) treatment was performed in a laboratory batch digester equipped with a mixing propeller. The temperature was raised from 50°C to 170°C in 95 minutes and the cooking temperature was maintained for 110 minutes. The alkali charge was 4.5 mol/kg NaOH and the sulfidity used in the cook was 35%. The liquor-to-wood ratio was 4 and the kappa number target was 30. Pulps were stirred at 30 rpm in order to ensure even alkali and temperature distribution during cooking. Mixing at 170°C and 130°C consisted of additional mixing starting 15 minutes before the end of the cook. This mixing was carried out at a speed of 350 rpm. The damaged pulps are designated DAM170 and DAM130. More information about this treatment can be found in [16].

Deformation treatment conditions

Pulp deformation was accomplished in two ways:

1) The unbleached pulp was deformed at 25% consistency for 30 min and then beaten for 2000 revolutions in a PFI beater. This pulp is designated H-pulp.
2) Unbleached and bleached pulps were beaten in a PFI beater for 2000 and 3000 revolutions respectively according to ISO 5264–2. Directly after the beating the pulp suspension was homogenized in the beating water (so as not to lose fines) using a Hobart kitchen mixer. Homogenization of bleached pulp was carried out at room temperature (25°C) and 8% consistency with a homogenization speed of 285 rpm for 60 minutes. Unbleached pulp was homogenized as for the H-pulp. These pulps are designated DEF and DEF-bl.

Fiber curl and amount of fiber kinks were measured from the fibers in the pulp suspension using a PulpExpert fiber analyzer.

Table 2 Bleaching conditions.

Stage	D_o	E_1	D_1
ClO_2 charge, %	6.2	–	2.9
NaOH charge, %	0.33	2.8	0.36
Temp., °C	50	60	70
Time, min.	60	75	120
Cons., %	3	8	8

Bleaching conditions

Both undamaged and damaged pulps were bleached using a DED bleaching sequence. Bleaching was performed in plastic bags to ensure that no mechanical energy was applied to the fibers. The bleaching conditions are presented in Table 2.

Measurements

Pulp properties were measured according to the following standards:

- Brightness ISO 2470
- Kappa number SCAN-C 1:00
- Viscosities SCAN-CM 15:99
- Beating was performed using a PFI beater according to ISO 5264–2
- Water retention value (WRV) SCAN-C62
- Fiber curl and kinks with a PulpExpert

We made handsheets according to ISO 5269–1 (60g/m^2 for unbleached and 40g/m^2 for bleached). The following properties were measured at 23°C and 50% RH:

- Wet and dry zero-span strengths according to ISO15361
- Fracture toughness, tensile strength, breaking strain and tensile stiffness according to SCAN-P 77:95
- Modified Scott bond measurement TAPPI T 833 to characterize z-directional fiber strength and/or bonding
- Tear index according to ISO 5270

Bleached REF, DAM130 and DEF pulps were studied in more detail. To characterize the effect of fiber deformations on the zero-span fiber strength with greater statistical reliability, 100 measurements were made for each test point.

RESULTS AND DISCUSSION

The pulp and fiber properties of unbleached damaged and undamaged pulps made from different softwood raw materials were measured, and the effect of the mechanical treatment on these properties is discussed below.

Cooking and bleaching results

Table 3 shows the cooking results from the experiments carried out in this study.

Table 3 Cooking results.

Raw material	Yield, %, total	Kappa number	Viscosity, ml/g	Brightness, %	Rest EA, g/l
Spruce undeformed	48.6	28.9	1270	27.2	5.1
Spruce damaged @170°C	49.7	27.4	1100	28.5	5.0
Spruce damaged @130°C (DAM130)	48.5	29.3	1260	27.28	6.19

The results show that there were small differences in kappa numbers between the pulps. The residual alkali after cooking was comparable for both undamaged and damaged pulps. The dry content measurement was not very exact because the pulps were not spin-dried. For this reason the yield determination was not very reliable. If compared at the same kappa number, the differences in viscosity between the undamaged and damaged pulps from the same raw material were moderate. The pulp damaged at 170°C had slightly lower viscosity. However, it is presumed that differences at this high viscosity level do not contribute to fiber strength properties.

The bleaching results for the undeformed and DAM130 pulps are presented in Table 4.

Table 4 Bleaching results.

Pulp	Kappa number	Brightness, %	Viscosity, ml/g	WRV, g/g
Spruce undeformed	1.97	77.3	1200	1.9
Spruce damaged @130°C (DAM130)	2.06	78.2	1130	1.61

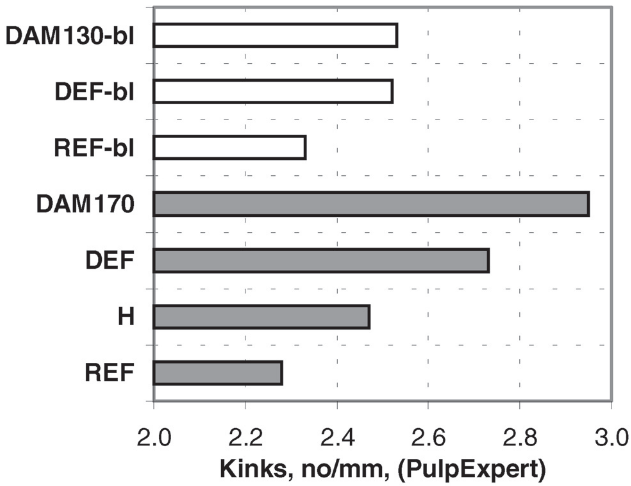

Figure 2 Fiber kinks for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs. Measured with a PulpExpert.

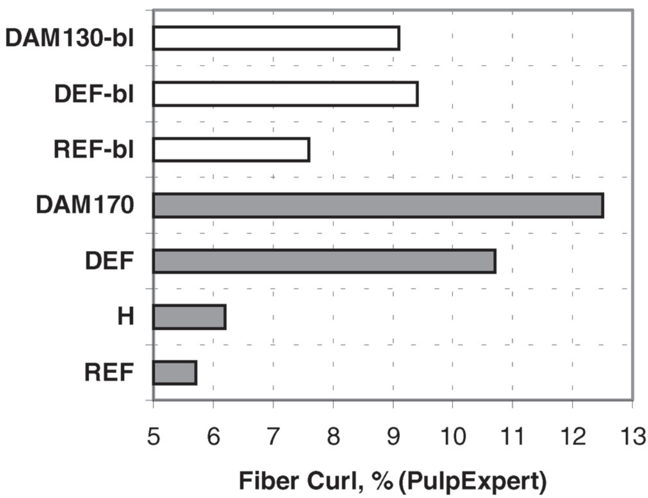

Figure 3 Fiber curl for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs. Measured with a PulpExpert.

It can be seen from the bleaching results that the kappa numbers and brightness values of the pulp sheets are about the same. The viscosity of the bleached damaged pulp is slightly lower than that of the undeformed pulp.

Fiber and fiber network properties

Figures 2 and 3 show the number of fiber kinks and fiber curl present in the differently treated bleached and unbleached pulps. The results show that the extent of fiber deformation is slightly higher for the bleached REF-bl pulp than for the unbleached REF pulp. Otherwise the bleached pulps exhibit less fiber deformation than the unbleached pulps. This is due to differences in the treatment conditions.

The results in Figure 4 show that fiber curl does not seem to affect pulp sheet density in the case of the unbleached REF, H and DEF pulps. However, the pulp sheet made out of damaged fibers DAM170 has a much lower density than the other pulp sheets. This is due to its lower swelling ability, seen as smaller WRV (see Figure 6), and thus smaller shrinkage in drying.

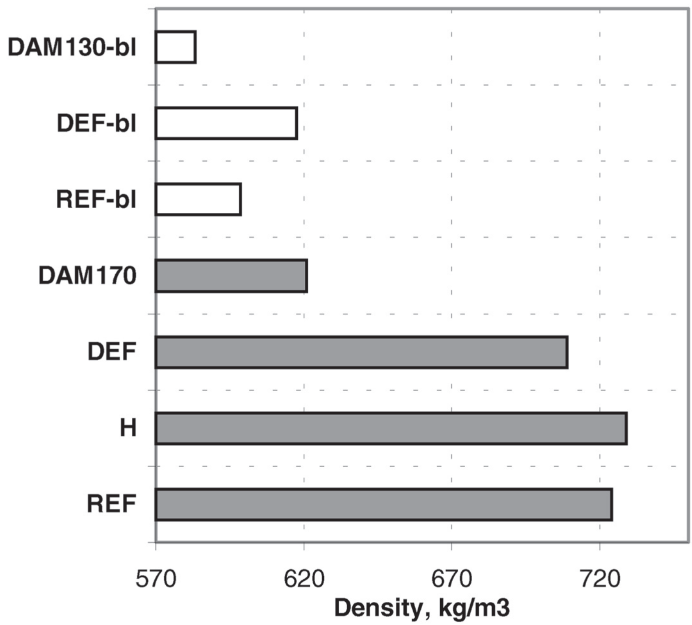

Figure 4 Densities for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs. Measured with a PulpExpert.

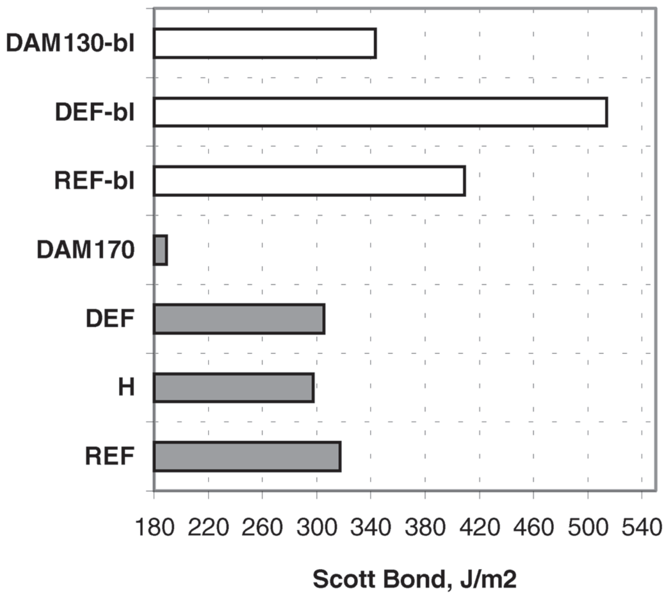

Figure 5 Scott bond for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs. Measured with a PulpExpert.

The Scott bond values of the pulps are shown in Figure 5. The pulp sheets made of bleached pulps have higher Scott bond values due to the higher degree of beating and their greater conformability. The Scott bond value obtained for the DEF-bl pulp is much higher than that of the other pulps. The reason for this is unknown. Similar treatment of bleached commercial fiber in [22] resulted in an increase in SR value. It may thus be that with bleached pulp deformation treatment causes fiber surfaces to experience the same kind of effects as in refining. The Scott bond and WRV values obtained for the damaged pulps DAM170 and DAM130-bl were significantly lower than for the REF/REF-bl pulps. The water retention values (WRV) of the pulps are presented in Figure 6. As can be seen, the WRV values were significantly lower for the damaged DAM170 and DAM130-bl pulps.

Figures 7 and 8 show tensile and stiffness indices for handsheets made from the differently treated pulps. The values for the bleached pulps are slightly lower due to deformation and damage treatment. The unbleached pulps REF, H and DEF, which have similar sheet densities and Scott bond values (Figures 4 and 5), have different tensile and tensile stiffness indices. With DAM170

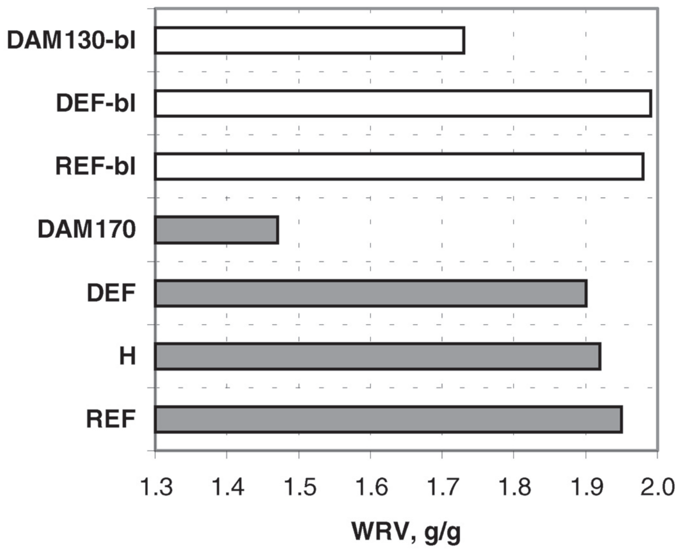

Figure 6 WRV values for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs.

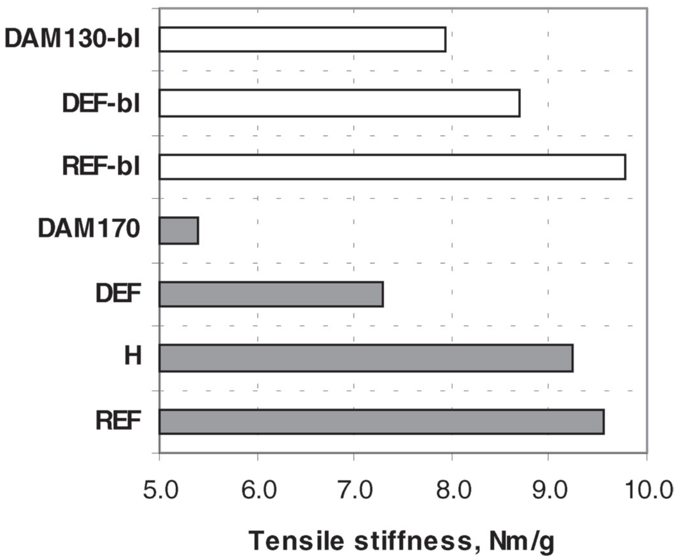

Figure 7 Tensile stiffness values for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs.

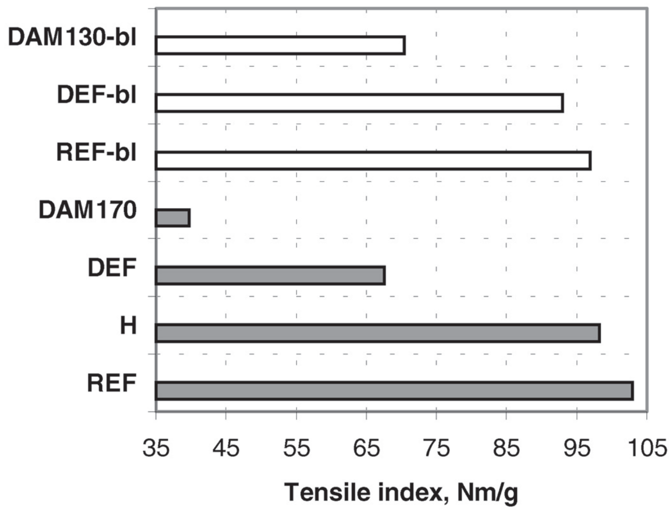

Figure 8 Tensile index values for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs.

these decreased dramatically. This can be explained by the fact that the deformed fibers (fiber curl, and kinks) form a fiber network in which the load distribution is non-uniform (fiber activation is not uniform) compared to a network with straight and undeformed fibers. Slag non-activated fiber segments do not carry loads, and fibers that do are subjected to stress concentrations. This results in low tensile stiffness index and tensile index values [16, 4, 5, 17].

The fiber strengths of the damaged DAM170 and DAM130-bl pulps were much lower than those of the corresponding REF pulps, Figure 9. The deformation treatment of the bleached and unbleached pulps did not greatly affect fiber strength, although a very slight decrease in zero-span measurement was seen. The fiber strengths of the unbleached REF, H and DEF fibers were all about the same when measured with the wet zero-span method. The damaged pulp DAM170 had a 30% lower wet zero-span value than DEF, although the extent of fiber curl was the same. A similar phenomenon was seen in the case of the bleached pulps (Figures 3 and 9).

Despite the lower fiber strength of the unbleached DAM170 pulp, it gave a 20–25% higher tear index than the REF and H pulps at the same degree of beating, Figure 10. This was probably due to its lower fiber segment activation. This effect was not clearly seen with bleached pulps, possibly due to

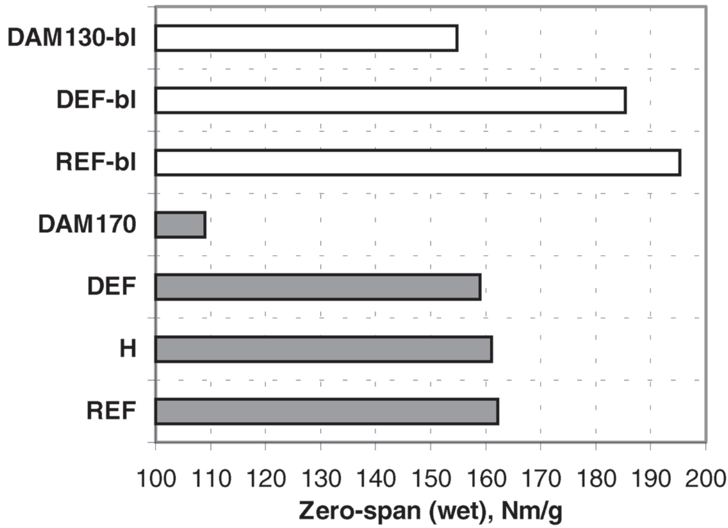

Figure 9 Zero-span tensile index values for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs.

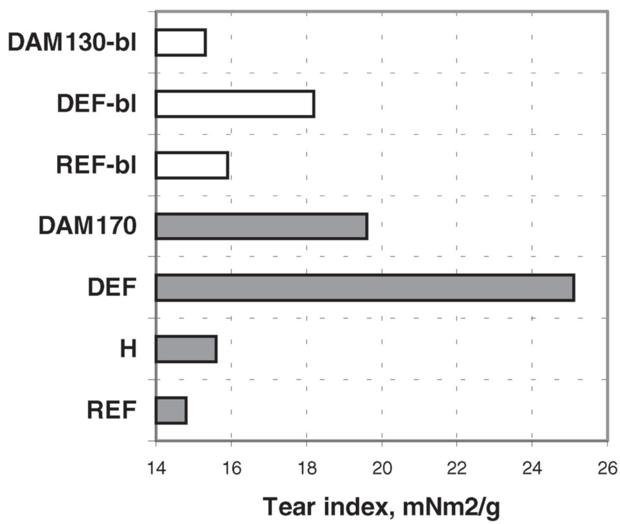

Figure 10 Tear index values for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs.

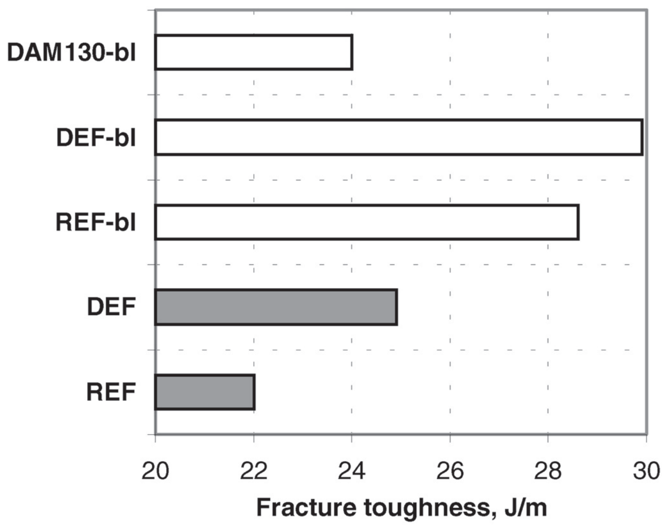

Figure 11 Fracture toughness values for the bleached (bl) pulps after 3000 PFI revs and for unbleached after 2000 PFI revs.

the small difference in the extent of fiber deformation. The fracture toughness of both bleached and unbleached DEF pulps was higher than for the REF pulp, Figure 11.

In-depth analysis of zero-span strength vs. fiber damage and deformations for the bleached pulps

Seth and Mohlin have argued that fiber strength should be measured from straight, well-beaten fibers (3000–4000 PFI revs) to obtain the real fiber strength using the zero-span measurement. Many authors have argued that the zero-span measurement should be done using straight fibers, because if fibers are curled they do not carry load in the measurement, which reduces the zero-span value. To confirm the result shown in Figure 7, we studied the bleached REF-bl, DAM130-bl and DEF pulps in more detail.

First, the fiber deformation levels shown in Figures 2 and 3 are given in Table 5 together with the fiber length and zero-span results.

Curl is presented as a function of fiber length intervals in Figure 12. It is evident that fiber curl differs at practically all fiber length intervals. Table 5 shows that fiber length is about the same for all the pulps. For the damaged DAM130 and deformed DEF pulps, the curl and kink values are about the

Table 5 Fiber length, average extent of fiber deformation measured with the PulpExpert, and dry zero-span strength of the beaten and bleached REF-bl, DEF-bl and DAM130-bl pulps. For zero-span values the 95% confidence interval is shown (n=100).

Pulp sample	Fiber length, mm (length weighted)	Fiber curl, %	Fiber kinks, no/fiber	Dry zero-span tensile index, Nm/g
REF-bl	2.54	7.6	2.33	197.1 ± 2.3
DAM130-bl	2.46	9.1	2.53	155.1 ± 1.6
DEF-bl	2.49	9.4	2.52	188.0 ± 2.1

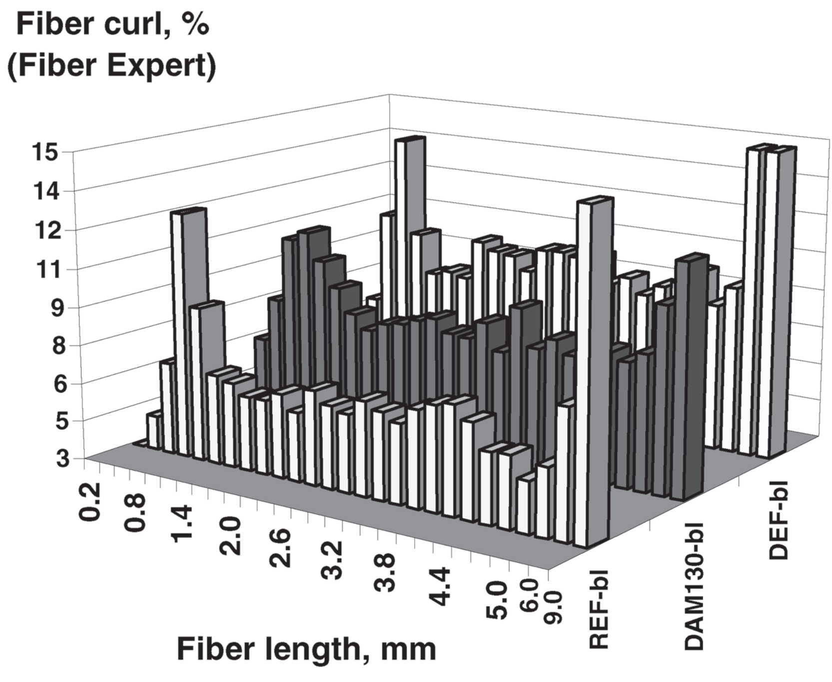

Figure 12 Fiber curl at different fiber length intervals (measured with the FiberExpert).

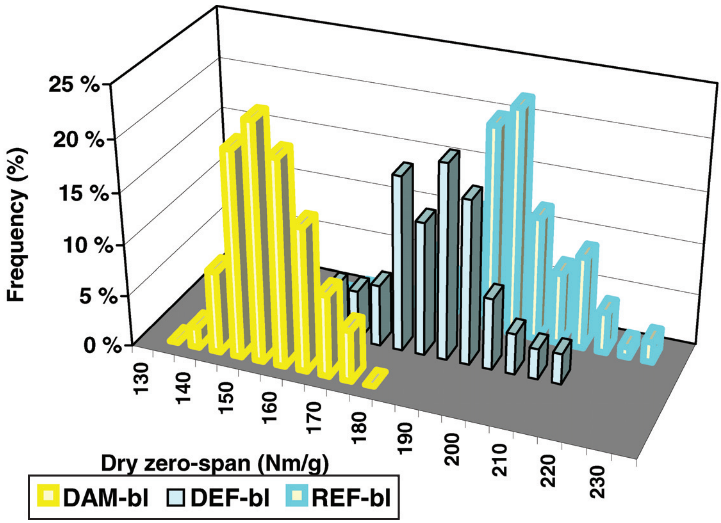

Figure 13 Dry zero-span histograms for bleached DAM-bl, DEF-bl and REF-bl pulps.

same. The huge difference in zero-span strength between the two cannot therefore be attributed to these measurable properties, but must come from internal deterioration of the fiber structure. Rather than the difference in curl, this deterioration arising from deformation treatment is probably responsible for the difference between the REF and DEF pulps. Figure 9 shows that, for unbleached pulps, a 100% increase in fiber curl, caused by deformation treatment, leads to a decrease of around 2% in wet zero-span. There is no reason why fiber curl would have a greater effect on zero-span measurements when bleached pulps are used. However, bleached pulps can be expected to be more prone to internal deterioration during the curling treatment. Fiber curl probably does not make a major contribution to zero-span fiber strength.

Figure 13 clearly shows that the zero-span strength distributions of REF-bl and DEF-bl zero-span values are higher than those measured for the DAM130-bl pulp. This is in accordance with the results obtained from the unbleached DAM170 pulps.

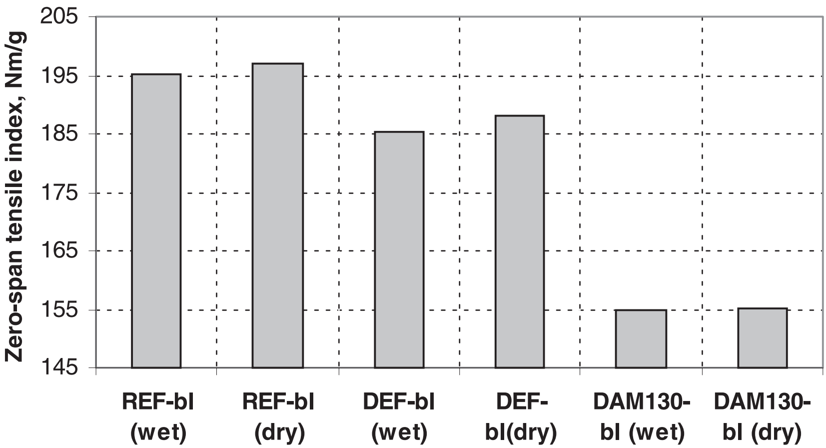

Figure 14 The wet and dry zero-span tensile index values measured for the DAM-bl, DEF-bl and REF-bl pulps.

The contribution of fiber damage and fiber deformations to fiber network properties can be divided in such a way that fiber damage defines the potential level of fiber network strength properties, while fiber deformations define the nature of the strength properties at a certain fiber bonding level. These properties can be adjusted by the requirements of the products concerned. As Figure 14 shows, there is little or no difference between the wet and dry zero-span measurements for the bleached DAM, DEF and REF pulps. Mohlin [22] has shown that wet zero-span measurement is more susceptible to visible fiber defects than dry zero-span. These defects make it possible for water to break hydrogen bonds within fibers, thus reducing wet zero-span fiber strength. In our case the fact that there was no difference between the measurements could be because the fiber surface is more or less unchanged while the fiber wall structure is weakened by mechanical action.

Runnability and deformed and damaged fibers

Runnability can be defined as the problem-free running of a paper web of the desired quality on paper machines, converting machines and printing presses. We think it is possible to use deformed fibers to improve runnability. For problem-free running, the essential properties of paper webs are tensile stiffness and its behavior on moistening, web uniformity (i.e. the absence of weak spots) and defect resistance. With deformed fibers, tensile stiffness is often compromised. This is not usually good. There may be compensating effects however. Since deformed fibers distribute load effectively, fracture energy increases, as we and others have shown. If the drop in tensile stiffness is not too drastic, the defect resistance of the paper web may actually improve. It can also be speculated that some CD profile-related runnability problems might be mitigated when the relative difference between the center and edge positions is lowered. If the converting process is run with constant speed differences instead of adjusting for proper web tensions, the greater breaking strain provided by the deformed fibers will help. Web uniformity is to a large extent defined by the paper machine construction and its operator, though short fibers naturally help in achieving good formation. Deformed fibers act here through the mechanisms similar to defect resistance: structural weak points are either reinforced or weakened.

Tear strength is still used, even today, to predict web runnability. However, Uesaka has demonstrated that tear strength does not predict runnability on printing presses [24]. Curly fibers lead to higher tear strength, as observed here and also by many other authors [4, 20]. There are claims, based on fracture mechanics calculations, that curly fibers give a paper web higher critical elongation, i.e. breaking strain of a web with a defect [20]. On the other hand, the same study shows that critical force (breaking tension) also decreases. Whether fracture mechanics can give accurate estimations of breaking tensions on the printing press is not clear [21], but qualitatively it addresses the relevant phenomena. Eriksson et al. [21] studied the ten different commercial kraft reinforcement pulps critical elongation and force. They observed practically no difference between the pulps. The pulps must have some difference between them in terms of damage and deformations, but any difference is obscured by other phenomena.

Tactile properties and deformed fibers

Much of the competitive edge enjoyed by paper over other media is due to the sensory satisfaction it gives the user. This, of course, depends on the tactile properties of the paper product: for example, what it feels like to riffle through the pages of a magazine. This is a relatively new area of study that definitely needs to be pursued if paper is to keep its place as an information platform. Deformed fibers can also be exploited in this area. Vihavainen [18] showed there is a strong statistical connection between instrumentally measured resistance to bending and how a person experiences the rigidity of papers. The same relationship was also found for roughness felt by people in relation to air permeance and roughness measured using instruments. Bending resistance depends on bulk and tensile stiffness, of which the latter is affected directly by fiber deformations. Deformed and damaged fibers may give potential for higher bulk. Forsell et. al. also found a connection between measured paper properties and those experienced by persons [19].

Paperboard and deformed fibers

According to Page, the fiber orientation of machine-made papers may be diminished by the use of curly fibers [4]. In many applications of boardmaking it is important that in-plane properties are closer to one another than for example in printing papers, since CD bending stiffness is a critical property [25]. This might be achieved through the proper use of curly fibers. Curly fibers also give a higher breaking strain, which is very beneficial to the top layer of cartonboard during creasing [25].

CONCLUSIONS

Deformations can be introduced into fibers before or after beating without significantly affecting fiber strength. Wet zero-span fiber strength is not dependent on the deformation method or on the extent of deformation. The pulp sheet density or Scott bond bonding measurement showed little or no dependence on the deformation type or method. The pulp sheet tensile properties were dependent on the extent of fiber deformation via fiber segment activation in the case of deformed pulps (H and DEF). The damaged pulp showed fiber deformation comparable to that for the DEF pulp but exhibited lower single fiber strength (measured with wet zero-span), together with lower bonding ability and sheet density. The tear index for the DAM pulp was 20–25% higher than for the REF and H pulps. Fiber deformations (curl and kinks) influence fiber network properties, but not single fiber shrinkage potential (WRV) or fiber strength. Fiber deformations affect fiber segment activation, i.e. fiber network properties. Fiber damage decreases single fiber strength. When fiber damage is induced, it is difficult to avoid some degree of fiber deformation.

ACKNOWLEDGEMENTS

We are grateful for financial support from TEKES via the Wood Material Science Research Programme (BUNDLE, Fibre wall modelling). The Finnish Cultural Foundation and The Jenny and Antti Wihuri Fund are thanked for financing Rolf Wathén's graduate studies.

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Transcription of Discussion

ROLE OF FIBER DEFORMATIONS AND DAMAGE FROM FIBER STRENGTH TO END USER

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Tom Lindström STFI-Packforsk AB

I think the graph Figure 6, where you show that the damaged fibres have a considerably lower water retention value is pointing to some kind of chemical effect occurring during cooking and then you speculate about what you call internal deterioration. Could you illuminate a little bit or speculate about what is happening here because it is obvious that you are not only mechanically damaging the fibres? It points to some structural/chemical change of the fibres.

Olli Joutsimo

Actually, in our earlier studies, we have analyzed the chemical composition. There are actually no differences in that sense.

Tom Lindström

What is happening then? What is the "internal deterioration"? This is, I think, a very important observation.

Olli Joutsimo

We have speculated that we are actually opening the pore structure in the cell wall in the sense that the tracer transfer is decreased. So if we are opening the pore structure, the pore structure is not able to hold the water inside the fibre wall as well, for example.

Tom Lindström

Have you done any further studies, for example not using water retention values, but measuring the fibre saturation point using solute exclusion?

Olli Joutsimo

Yes, we have done that and it points in the same direction.

Heinrich Baumgarten

You have produced chemical pulp and you have measured water retention value in the normal laboratory situation and then you have produced your sheet in a laboratory sheet former?

Olli Joutsimo

Yes, it was a standard sheet mould.

Heinrich Baumgarten

So the pressing pressure you used was very low, not comparable with the pressure used in a paper machine wet press, is that right? This higher pressure changes the fibres so strongly that you cannot compare the effect with laboratory results. You cannot investigate any influence of kinks and other problems.

I would like to make a remark about what we have heard sometime ago about crossing of fibres in the paper produced on a paper machine. We saw the fibres still swollen with an open lumen and in fact and in the industry these fibres will always be collapsed.

We heard that it would be good if the paper has no air volume. That would be a good paper. You can produce glassine paper like this, but it would be difficult to produce other kind of papers like this. You must understand that paper is fibre reinforced air and at least 50% of the volume is air and that is the big advantage of paper.

Olli Joutsimo

Thank you for the comment.

Harshad Pande Domtar Inc

I had a question about your pulp, DAM170, which is damaged at 170°C. Now, this pulp had a high curl and a high bulk. If you were to make a pulp at 130°C how would this be? I understand you have a pulp which is bleached at 130°C?

Olli Joutsimo

DAM130 is damaged at 130°C. It is bleached after damaging.

Harshad Pande

And it has a lower curl?

Olli Joutsimo

Yes, it has.

Derek Page JPPS

Thank you for that reference that you gave, the 1935 one. That was one that we missed during our survey, but I would like to comment on the apparent effect, or lack of effect, of curl on zero-span strength, which is definitely not in line with many of our research results. I am not too sure though how curly your fibres were. You have not shown us any images of the fibres and I do not know how the Pulp Expert value, translates into the measurement that I would have made. But it looks to me as though you did curl the fibres in the Hobart mixer and then you put the pulp into the PFI mill for 2000 revs which generally has the affect of taking out the curl. So, I do not know whether all this can be sorted out and whether our results are different from yours or the same as yours, because I do not know what your curl value means.

Olli Joutsimo

Actually, I have looked at these fibres under the microscope and it seems that they have been especially deformed and damaged. The damaged fibres are much curlier compared to those of the reference pulp.