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EFFECTS OF FURNISH-RELATED FACTORS ON TENSION AND RELAXATION OF WET WEBS

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ABSTRACT

A smooth web transfer in a paper machine requires sufficient tension. It is well known that excessive tension leads to web breaks. However, too low a tension can also be fatal. Particularly with wet web, the maintenance of the tension is challenging due to the fast relaxation of the tension. Some factors that affect the tension and relaxation of wet web were studied in this paper.

The initial tension and the tension after constant relaxation time, called residual tension, was found to depend on factors such as the applied strain, straining rate, dry solids content, fibre and fines properties, substances in the white water, and the dry strength chemicals. The residual tension was reduced by increased straining rate, addition of TMP filtrate, and addition of cationic starch. The tension and residual tension seemed to be dependent on both the properties of the fibre fraction, such as in- and out-of-plane stiffness, and on the factors affecting the stress transfer conditions at the inter-fibre contact areas.

INTRODUCTION

Wet web runnability

The effects of furnish composition, fibre properties and different papermaking chemicals on the tensile strength and elongation of wet paper have been widely studied. The tension generally, and especially the relaxation behaviour, of wet paper is an area that has not gained much attention. An essential motivation for determining wet web strength of paper furnish has been its effect on the runnability of paper machines. For example, Mardon *et al.* [1] found a correlation between the wet web tensile strength of mechanical pulps and runnability in newsprint machines. But the correlation was poorer with the wet web strength of softwood kraft pulps. This suggests that the correlation depends on the furnish and on factors related to the paper machine. In addition to wet web tensile strength, the stretch has also been considered important, as well as the work to a given stretch [2]. Seth [3] proposed that the combination of wet tensile strength and stretch can be used for estimating the runnability potential of furnishes. For this purpose he used the failure envelope, an envelope curve determined from the strength and stretch values measured over a range of moisture contents.

More recently new, partially complementary aspects have been emphasised. The runnability of paper in printing room has been shown to be affected by the low tension zones of the web [4]. Also with wet webs the low tension has been found critical [5–6] particularly because the tension tends to relax at a high rate.

Over the years the paper machines has experienced structural changes, there are no free draws before or within the press section, the remaining free draws after press section have become shorter, and the web is drier and it is generally supported by fabric. This has led to increased paper machine speeds and higher importance of aerodynamic flow patterns near the web [7]. Let us look closer at an example of web transfer (Fig 1) after wet press section. In the short free draw (A–B) the web experiences an elongation within milliseconds, determined by the speed differences of these consecutive rolls. The

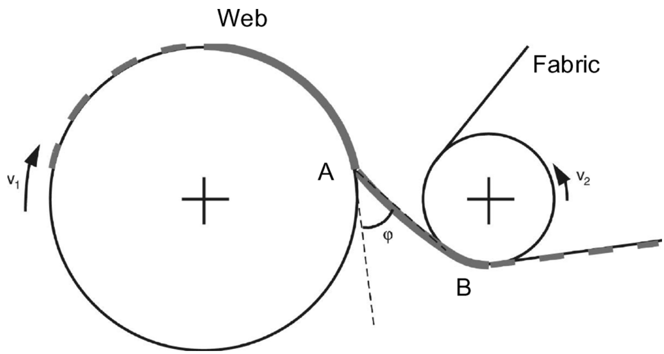

Figure 1. Web transfer in a free draw between press section and drying section [9].

strain typically varies in the range of 1–3%. The elongation raises the tension in the web to a level needed to ensure a stable web transfer. However, after point B, the web follows the fabric and the tension starts to relax. The web tension should remain at a reasonable level to minimise the instability phenomena in the drying section schematically illustrated in Fig 2. The main concern is usually focused on the cylinder opening nip where the web should follow the drying fabric but often tends to follow the cylinder surface, which can lead to wrinkling and web breaks [8]. Despite the use of runnability elements, such as blow boxes the role of web tension is essential.

With modern high-speed paper machines, the air flows and the air associated with the running web and fabric can be assumed to be a major cause of poor runnability and large part of the web breaks are – not due to too high, but due to too low web tension. The reason for low web tension can be seen the inability of the web to create and maintain tension. As much as 50–70% of the initial tension in the wet web may be lost due to relaxation during the first 0.5 seconds after stretching paper by 1–2% [5–6]. Therefore, equipment capable of imposing a predetermined elongation at a high strain rate on the sample and for measuring the tension and its fast decay is needed.

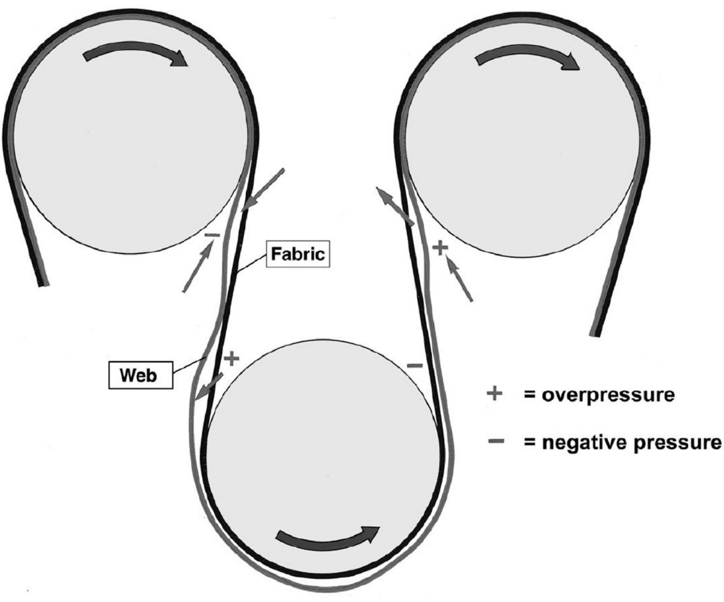

Figure 2. Instability areas in a single felted drying section [10].

Factors affecting the strength of wet webs

In the literature, the focus has generally been to measure the tensile strength of the wet web; very little data is available regarding factors affecting the elastic modulus and tension of the web. In the next section we look briefly at the factors that have been found to affect the tensile strength of wet webs.

One of the most essential variables affecting wet web strength is the moisture content of paper [11]. Wet web strength can be fitted to a power function of moisture over a wide range of moisture contents. The surface tension forces are assumed to be responsible for the wet web tensile properties over a wide range of solids contents (~20–60%) [13]. Fibre length and coarseness [14], fibre shape [15], amount and quality of fines [16–18] have been shown to affect the wet web strength. Generally, chemical pulp has been evaluated to give better wet web strength than mechanical pulp [11,19], and low-consistency beating of chemical pulp has been found to have a positive [11] and high consistency refining a negative effect [11] on wet web strength of chemical pulp. The surface tension [11] and temperature of the web [21] also have a definite effect, as do the papermaking chemicals applied. Often the conventional chemicals have negative effects but chemicals containing for example, aldehyde groups that are capable of making cross-links in a wet environment improve wet web strength [21–24].

Generally the strength of wet webs is affected by similar factors as strength of dry paper. There are, however, definite differences. Fibre strength can be important for dry paper, but it is of low importance for wet paper. This is because the fibres are much stronger than the stresses transmitted to them through the inter-fibre contacts. On the other hand the fibre geometry and morphology related factors are important, as well as the factors related to the phenomena at inter-fibre contact areas. The recent advancements in the fibre-polymer interaction studies have raised new insights into the molecular level phenomena taking place at the inter-fibre contacts [25]. An introduction of cationic polyelectrolytes to fibres is often detrimental to the wet web strength because swollen fibres cannot develop close contact due to steric or electrosteric repulsion resulting from a layer of dissolved polymers covering the fibre surface.

The theoretical approach for wet web strength has been exercised by several authors. Page [26] and Shallhorn [13] have modified and used the "Page tensile strength equation" for estimating wet web strength. The Young's modulus and straining behaviour of wet paper has also been simulated [27–28]. Varying such properties as the fibre stiffness and shape causes changes in the network stiffness and elongation at break, but has little impact

Table 1. Examples of factors affecting the tensile strength of wet web [6–26].

Factor	*Effect*
Dry matter content	+
Fibre length	+
Fibre coarseness	–
Fibre curl	–
Amount of fines from mechanical pulp	+
Quality of fines from mechanical pulp	
– fibrillar fines (vs. flake-like fines)	+
Surface tension of water	+
Chemical pulp (vs. mechanical pulp)	+
Strain rate	+
Beating of chemical pulp	+
Increased temperature	–
Papermaking chemicals	
– conventional starch	–
– aldehyde starch	+
– chitosan	+
– G-PAM	+

on the network strength. The out-of-plane shear of fibres appears as one important mechanism involved in stress transfer between fibres during tension.

Objectives of this study

As very little information has been published on the factors affecting the tension and relaxation of wet webs, in this study the effects of certain furnish-related factors on tension and relaxation of wet paper on a short time scale have been examined. A laboratory test device using an elongation rate of 1 m/s was used. Paper samples were strained to a predetermined strain and the decay of the tension was recorded. The tension measured after a constant time of relaxation is called residual tension. Residual tension is assumed to be a good indicator for tension holding ability and runnability of wet web after press section and at the beginning of dryer section.

The objective of this study was to determine the effect of furnish and white water related properties on the tension and relaxation characteristics of wet web. The effects of dry solids content, strain rate and amount of straining were also determined.

EXPERIMENTAL DETAILS

Sample preparation

Handsheets of 60 g/m^2 were formed from different pulps using white water recirculation. Sheets were formed according to the SCAN standard. The dry solids content of the samples was varied by wet pressing pressure. Typically the sheets were pressed at two different pressures (50 kPa and 350 kPa) in order to reach two different dry solids content levels.

Measurement of tension and relaxation properties

Tension and relaxation properties of the samples were measured with fast tensile test rigs using elongation velocities up to 1 m/s. For paper samples having a span length of 100 mm this equals a strain rate of 1000%/s. Tension and residual tension values were measured in each case from 10 strips. The span length of all paper samples used was 100 mm and the width of wet samples was 20 mm.

The amount of strain was measured with a laser sensor. The wet samples were typically measured at 1% and/or 2% strain levels. The highest tension after straining is called maximum tension (or initial tension in the relaxation test phase). The relaxation time used for wet samples was 0.475 s. The tension after this relaxation time is called residual tension, which describes the tension holding ability of paper at constant strain level. An example of a relaxation curve is presented in Figure 3.

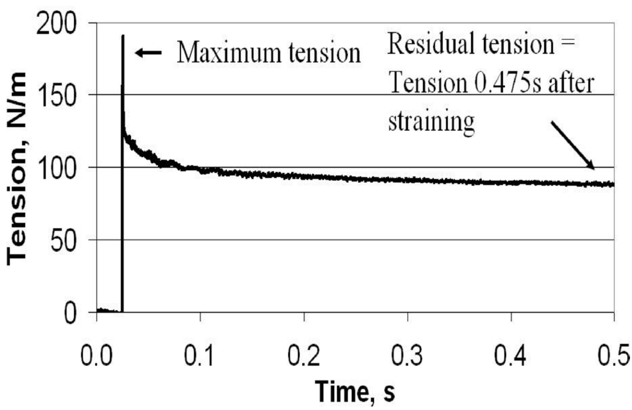

Figure 3. An example of a relaxation curve of wet web.

Fractionation of pulps

The pulps used in the experiment were a once-dried commercial bleached softwood kraft pulp and softwood TMP pulp (latency removed, CSF 45), both pulps from Finland. The bleached kraft pulp was beaten in a Valley beater to 500 CSF (25 SR). After beating, the pulp was fractionated. The long fibre fractions (R25) were separated with Bauer McNett apparatus. Fines were separated from the pulps manually using a 200 mesh screen. As the chemical pulp contains only a limited amount of fines, the fines used for the additional experiment were separated from pulp beaten to SR 75 in a Valley beater.

White water composition

The effect of white water composition was studied with handsheets made of bleached chemical softwood pulp beaten to SR 25. In the reference case deionised water was used. Also TMP filtrate from TMP mill was collected. Additionally, synthetic surfactant that is used in the deinking process, defoamer used in paper mills, and a "model extractive", oleic acid were used. The chemicals were added both to the recirculation water and water used for diluting the pulp suspensions for sheet making.

Samples:

- Deionised water
- TMP filtrate after peroxide bleaching from TMP mill, pulp diluted in deionised water at a 1:6 ratio
- 100 ppm surfactant Liptol S-100, (Brenntag Nordic Oy)
- 100 ppm oleic acid ($C_{18}H_{34}O_2$) (Sigma-Aldrich 75093)
- 100 ppm defoamer De-Airex 7061, (Hercules)

Application of starches

Conventional commercial cationic starch (Raibond 15) and experimental dialdehyde starch (molecular weight 21,100 g/mol) made by VTT were applied onto wet handsheets. The starches were applied by spraying 0.5% solution onto the sheet on a vacuum table. The starch addition was 10mg/g of pulp. The reference sample was also sprayed with an equivalent amount of water. The spray application method was selected in order to reduce potential differences in starch retention.

RESULTS AND DISCUSSION

Dry solids content and strain rate

Like tensile strength and elastic modulus also the residual tension of wet paper increases in an exponential fashion when dry solids content is increased (Fig 4). An exponential relationship has been found to apply with all samples studied and therefore an exponential fit has been applied in analysis of all the results.

Compared to the tensile strength the residual tension at 1 and 2% strain is low. At 2% strain residual tension is on average 23% and at 1% strain about 14% of the tensile strength. Increasing the strain from 1% to 2% also increases the residual tension, but only by 55–71%. The residual tension is also strain rate dependent and it can be considered to be closely related to the maximum tension (initial tension of the relaxation phase) and we might expect that higher strain rates give higher maximum tension and residual tension. This is, however, not the case. The maximum tension is increased with increasing strain rate, but the residual tension is decreased (Figure 5). This indicates that the stress distribution induced by a fast straining phase favours faster stress relaxation. This also suggests that short free draw may lead to faster relaxation and lower web tension.

Furnish composition

Papers made of chemical pulps generally have better dry strength and wet strength than papers made of mechanical pulp. This was also found to be the case here (Fig 6), but the amount of fines also has a definite increasing effect.

Fig 6 shows that the initial wet strength is increased when fines either from chemical or mechanical pulps are added to long fibre fractions, but the kraft fines are considerably more efficient in improving the wet web strength than the TMP fines. The softwood kraft fibres combined with kraft fines give the highest strengths, but adding kraft fines to TMP fibres also has a very positive effect. This suggests that the kraft fines with higher specific surface area, fibril content, and lower lignin content [18,29] improve the stress transfer between fibres. Compared at the same kraft fines content the figure shows that softwood kraft fibres give better wet strength than TMP fibres. The difference is not caused by fibre length, as the fibre lengths of these pulps were very similar (TMP 2.1 mm, kraft 2.0 mm), but we can assume that an important factor is the higher number and higher surface area of kraft fibres in the sheet, which is due to their lower coarseness (0.25 mg/m vs. 0.18 mg/m, respectively).

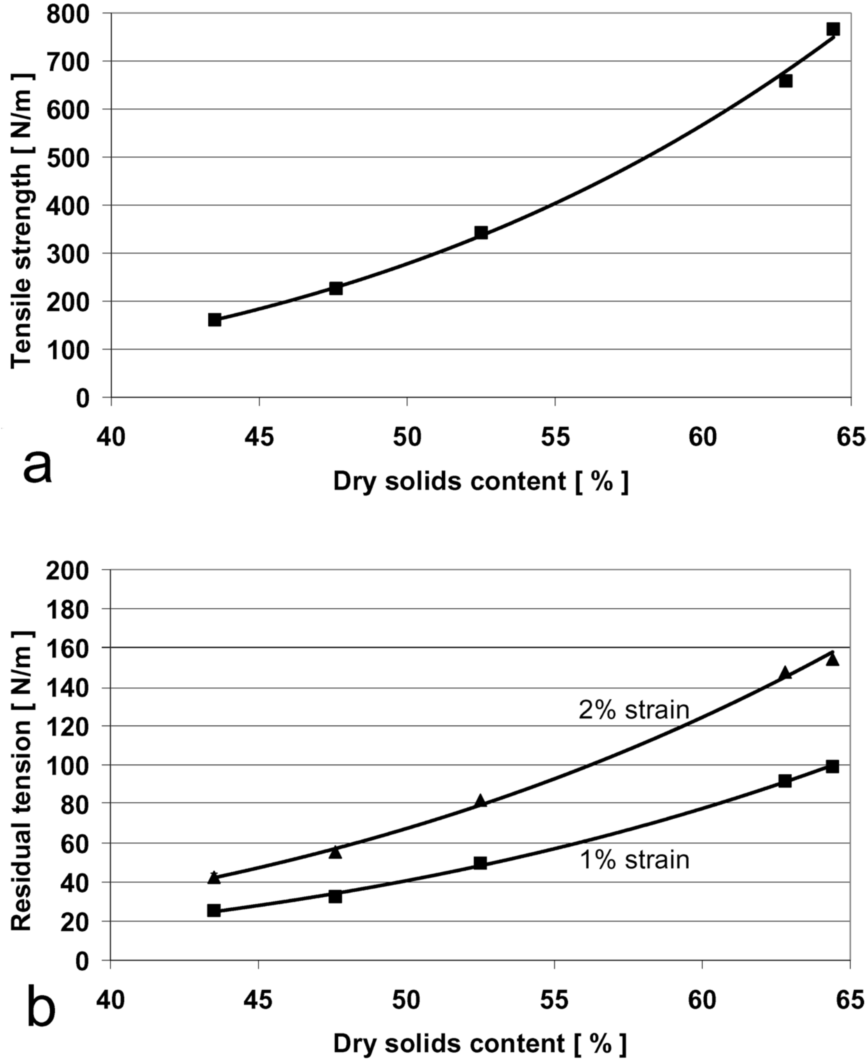

Figure 4. The dependence of a) tensile strength and b) residual tension (at 1% and 2% strains) on dry solids content of chemical pulp.

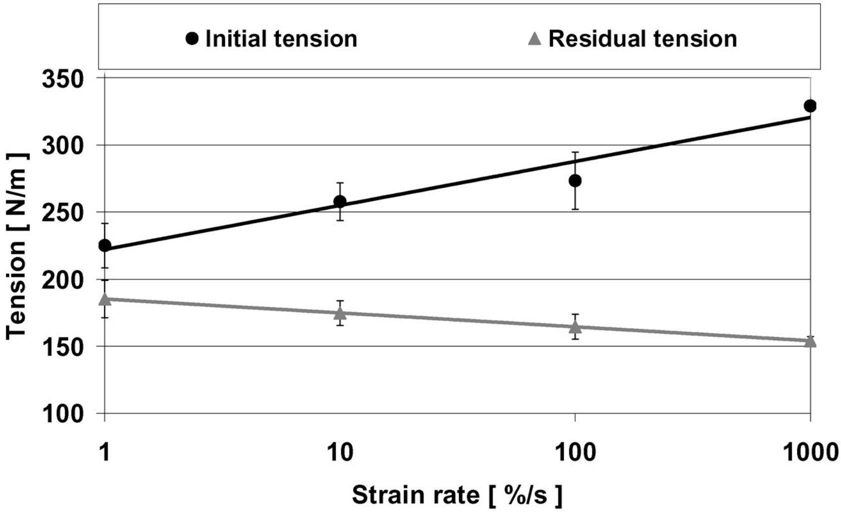

Figure 5. The dependence of maximum tension (initial tension) and residual tension on strain rate (bleached softwood chemical pulp) at 2% strain.

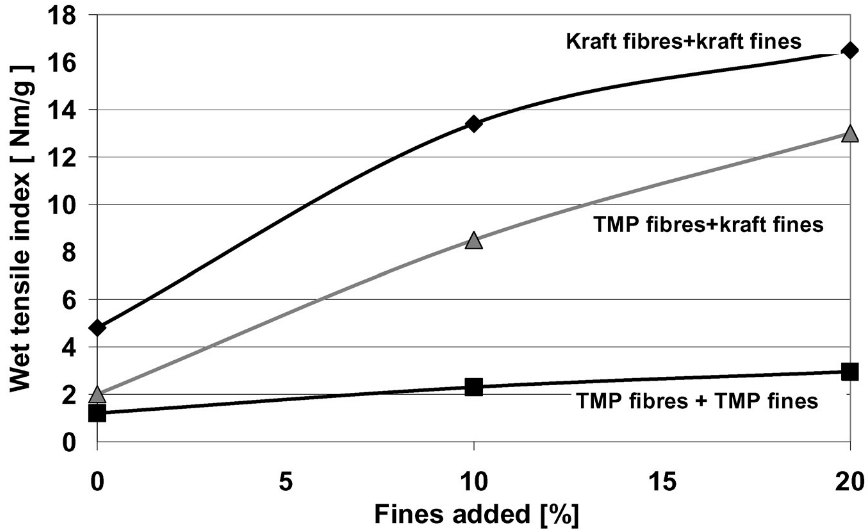

Figure 6. The dependence of initial wet strength on the amount and type of fines and fibres (at constant 350 kPa wet pressing pressure).

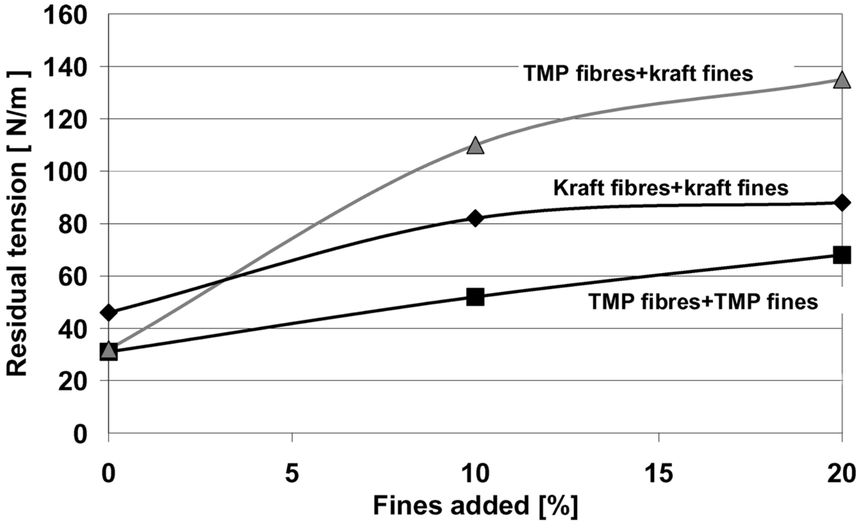

Figure 7. The dependence of residual tension at 1% strain on the amount and type of fines and fibres (at constant 350 kPa wet pressing pressure).

From Fig 7 we can observe that the addition of fines, and especially kraft pulp fines, also has a strong improving effect on the residual tension. But unlike tensile strength, the TMP fibres with kraft fines seem to give considerably better residual tension than kraft pulp fibres. This suggests that the TMP fibres can utilise the improved fibre-fibre interactions brought about by the kraft fines in a much better way than kraft fibres. The high residual tension of the TMP – kraft fines blend is surprising if we consider the higher fibre coarseness and lower number of fibres per gram in the TMP fibre network.

The previous comparisons were made after constant wet pressing pressures. However, the addition of fines tends to reduce the dry solids content after constant wet pressing pressure. When we compare the residual tension values at constant dry solids content of 50%, the efficiency of fines is still more distinct (Fig. 8a). The addition of 20% TMP fines to long fibre fraction of TMP increases the residual tension by 170%. The addition of kraft fines has a still larger effect; the residual tension is increased by 600%. Although the initial level is rather low, we can deduce that the large increase is mainly due to the improved interaction and stress transfer of fibres at their contact areas, and chemical pulp fines are clearly more effective in improving the interaction than mechanical pulp fines.

The residual tension of the pure TMP fibre sheets (Fig 8b) is lower than

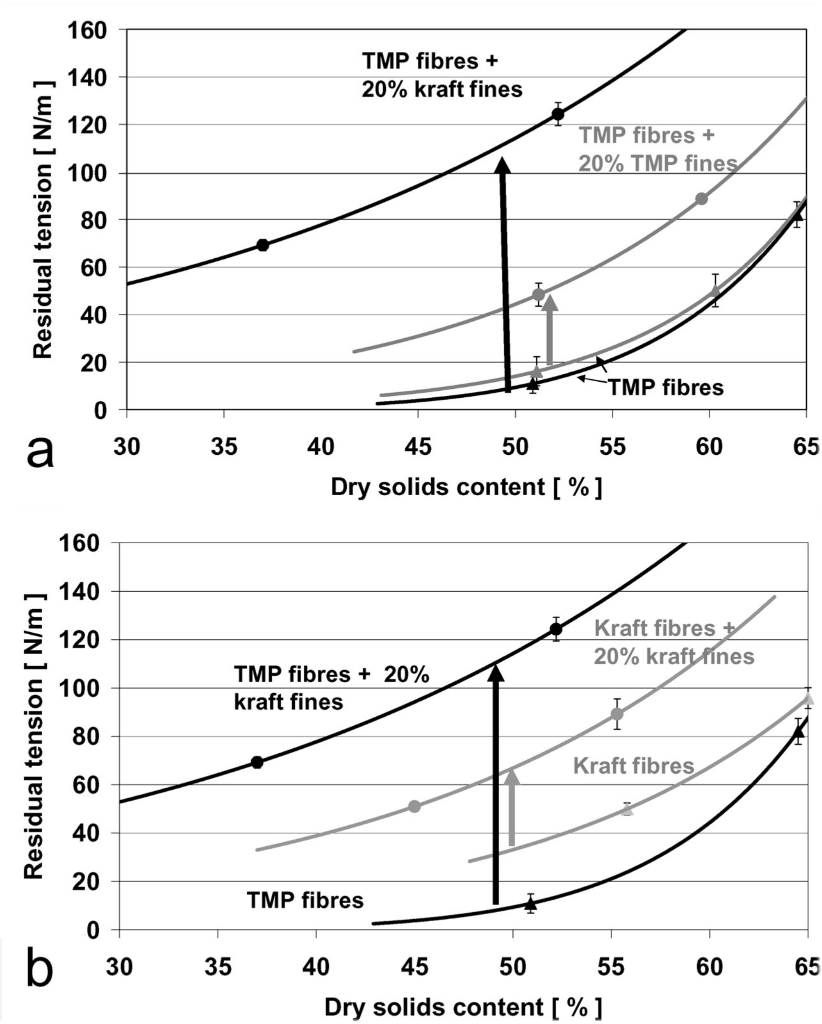

Figure 8. a) The effect of TMP and kraft fines addition on the residual tension of TMP fibre fractions; b) The effect of kraft fines addition on the residual tension of TMP and kraft fibre fractions. The comparison is made at 1% strain, and on two wet pressing levels at 0.05 MPa and 0.35 MPa.

that of pure kraft fibres but the addition of 20% kraft fines to TMP fibre fraction gives 80% higher residual tension than the addition of 20% kraft fines into kraft long fibres. Based on these results we can predict the difference between mechanical and chemical pulps. It can be assumed that 'kraft fibre' fraction is close to a typical chemical pulp and 'TMP fibres +20% TMP fines' is close to a typical TMP pulp. These results suggest that the residual tension of TMP would be clearly better than that of kraft pulp. This has also been found earlier [5–6].

The previous results show that wet TMP fibre network with 20% fines after straining it to 1% strain can have higher residual tension than the kraft fibre network. But is this difference due to different initial tension or a different rate of relaxation? In Figure 9 we can take a closer look at the percentage amount of the initial tension that has relaxed during the 0.475 s, here called the relative amount of relaxation. Generally, increasing dry solids content decreases the relative relaxation. Comparing the TMP and kraft fibres at 50% dry solids content, we can observe that the relative amount of relaxation of the TMP fibre network can be reduced from 85% to 60% by adding 20% kraft fines. With the kraft fibre network, the addition of 20% kraft fines reduces the relative relaxation from 65% to 60%. It seems that in a network which has good interaction between fibres, the relative amount of relaxation is 60% or less. In a more loose fibre network the relative relaxation is higher, but it can be reduced by strengthening the stress transfer by increasing dry solids content or adding fines. This indicates that the relative amount of relaxation is predominantly determined by the properties of inter-fibre contacts.

In TMP and kraft fibre networks containing 20% kraft fines (Fig 9), the relative amount of relaxation is almost the same although the residual tension was clearly higher for TMP (see Fig. 8). This means that the initial tension of the TMP network has been considerably higher. This means also that the high initial tension is the primary reason for the differences in residual tension of well connected wet fibre network. One probable explanation for the superiority of TMP fibres is the high wet stiffness, including in-plane and out-of plane shear stiffness, which also results in a fibre network with straighter fibres which have fewer bends and out-of plane undulations.

White water composition

White water properties and the dissolved substances that it contains are known to affect strength of dry paper. There are, however, no studies showing any explicit connection with wet web properties, or tension of paper. Figure 10 shows the effects of certain chemicals typically found in white water on the initial and residual tension of bleached softwood kraft pulp. Even when

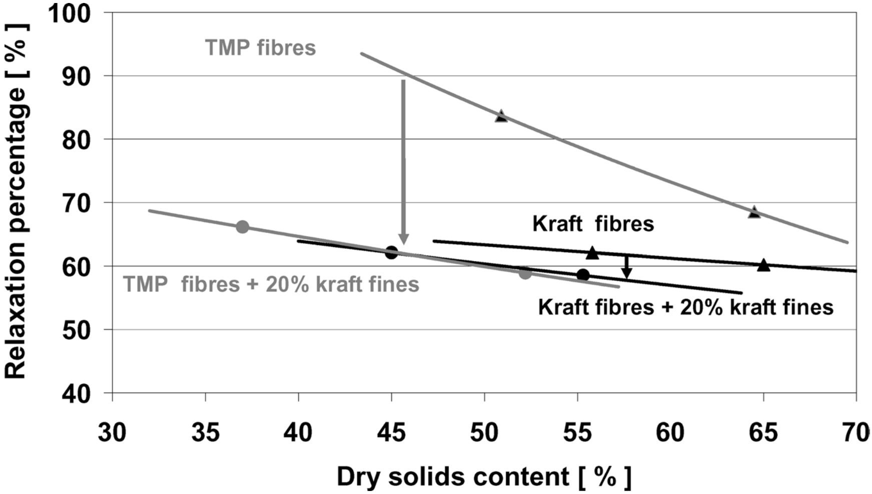

Figure 9. The effect of fibre type and addition of 20% kraft fines on the relative amount of relaxation.

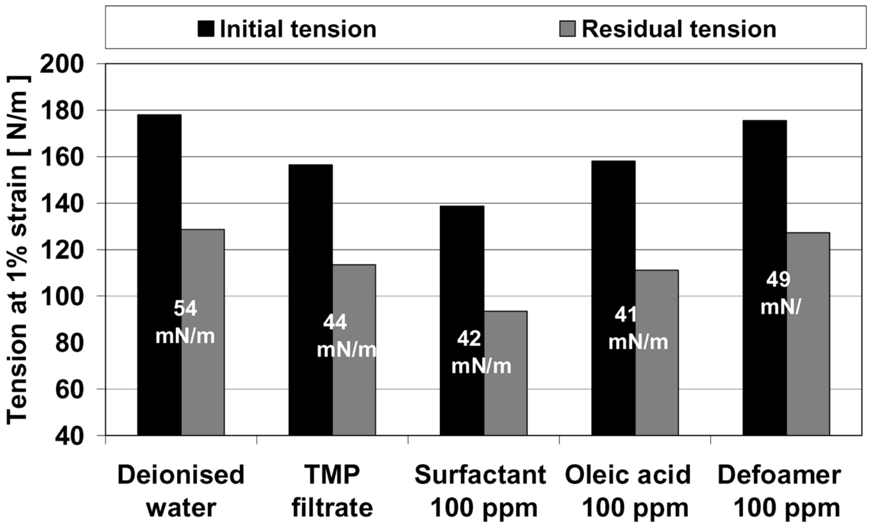

Figure 10. The effect of different substances in white water on the tension and residual tension at 55% dry solids content and at 2% strain (left).

deionised water is initially used the gradually dissolved chemicals accumulate during the recirculation and reduce the surface tension of the white water. When filtrate from the TMP plant was used the surface tension of white water, the initial and residual tensions (at 55% dry solids content) were reduced. On a fixed dry solids content level the trial points made with white water containing initially deionised water and then deionised water with defoamer gave the highest residual tension values and highest surface tension. An addition of 100 ppm of surfactant into water lowered residual tension considerably at a constant dry solids content, but greatly enhanced water removal in wet pressing and increased dry solids content by several percentage points (Fig 11) which had a positive effect on the residual tension.

Chemical additives

Chemical additives, such as starches, are used to improve the strength of dry paper. However, the wet web strength is not necessary improved. The residual tension of wet handsheets was also reduced by cationic starch addition (Fig. 9). This can be assumed to be due to properties of the fibre contact areas. Starch retains water, forming a gel-like material, and at this dry solids content the starch does not yet form chemical bonds. Additionally, the steric and

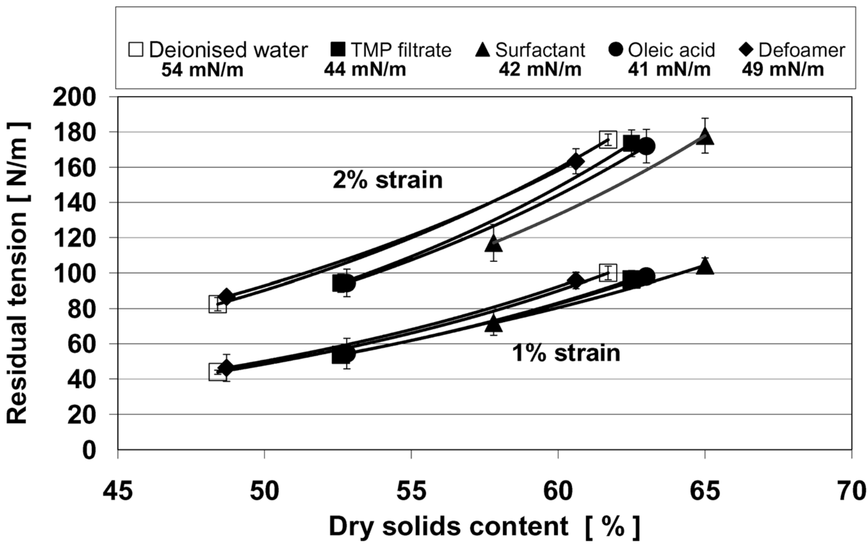

Figure 11. Effect of different substances in white water on the dependence of residual tension on dry solids content.

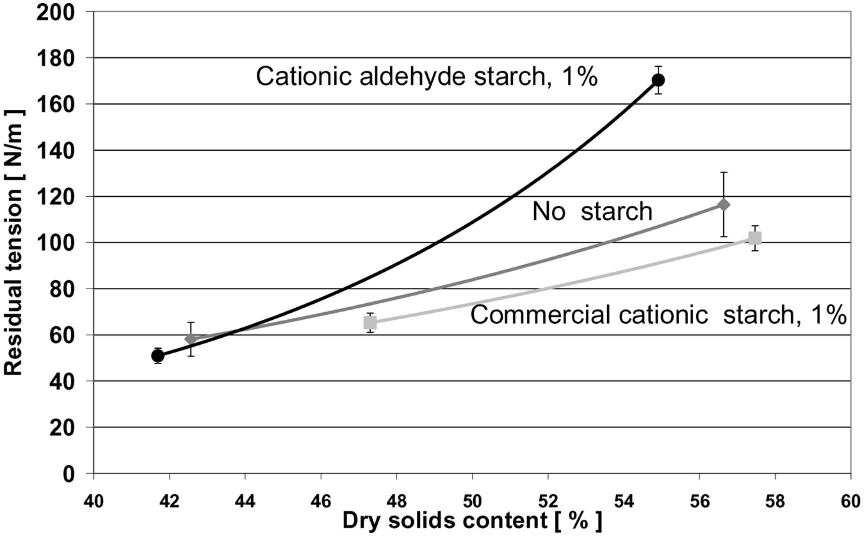

Figure 12. The effect of cationic starch and cationic aldehyde starch on residual tension of wet web at 2% strain.

electrosteric repulsion may play a role, resulting in reduced friction between fibres. Unlike conventional starch, cationic aldehyde starch significantly increased residual tension. The increase is greater with higher dryness levels. The difference between these starches is due to reactive aldehyde groups of the aldehyde starch which form acetal and hemiacetal bonds between fibres even under wet conditions. Similar results with wet web strength have been obtained by Laleg *et al.* [22].

Previous results show that the effects of wet end chemicals on the tension and residual tension of wet paper can be opposite to those they have on dry paper. The mechanical properties of wet fibre are different than those of dry fibre, and additionally the stress transfer in paper between fibres is largely due to molecular interactions that are different in wet and dry paper.

CONCLUSIONS

1. Tension and residual tension of wet web are properties that are closely related to the runnability of paper in a high speed paper machine. They are affected by similar factors as dry strength, but their effect can be the inverse.

2. Tension and residual tension in wet paper depend on the extent of applied strain, straining rate and dry solids content of the web. The initial tension was found to increase but residual tension decrease with the increasing straining rate.
3. Fines of both TMP and kraft pulp have beneficial effects on the strength and residual tension of wet web, but the kraft pulp fines are distinctly superior. The effect of fines can be assumed to be due to strengthened interaction and stress transfer at fibre contacts.
4. The TMP fibres are better than the kraft pulp fibres, probably due to their higher in- and out-of-plane stiffness. The highest residual tension can be obtained with a TMP fibre network containing chemical pulp fines.
5. The results indicate that the initial tension at certain strain is predominantly determined by the fibre properties and the relative amount of relaxation by the stress transfer properties of the fibre contacts.
6. Even small amounts of dissolved and colloidal substances typically found in white water can have a negative effect on the strength and residual tension of wet paper at certain dry solids content. Part of the effect can be explained by reduced surface tension. Reduced surface tension, however, also can result in increased solids content after wet pressing, which can override the negative effect.
7. Certain conventional dry strength chemicals, such as cationic starch, may have a negative effect on the tension and residual tension of wet paper, whereas cationic aldehyde starch can have a very positive effect. The molecular-level phenomena at fibre contact areas seem to play a central role.

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EFFECTS OF FURNISH-RELATED FACTORS ON TENSION AND RELAXATION OF WET WEBS

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ERRATA

In figures 6 and 7 the figure shows the values at constant 55% dry solids content, not after constant wet pressing pressure.

In figure 12 the upper curve is for dialdehyde starch, not for cationic aldehyde starch.

DISCUSSION

Torbjörn Wahlström StoraEnso

You referred to some work in the beginning that showed instability of webs in the dryer section. Have there been any pilot trials showing a relationship between residual tension and real runnability in the beginning of the dryer section?

Elias Retulainen

I have a figure here (see overleaf), which I showed in my presentation, but was not included in the preprint:

It is not an explicit verification that runnability will be better. There are these runnability elements here in the drying section that create some vacuum that tries to prevent this kind of baggyness of the web. This shows that the

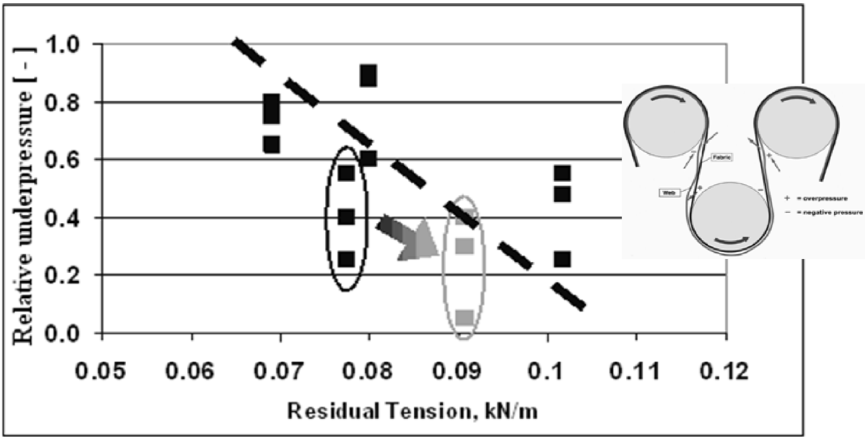

Figure 1. Correlation between the measured residual tension of the LWC base paper furnish and the stabilizing pressure of the runnability component in the first cylinder group of the pilot machine. The measurement of the residual tension has been made from samples taken after wet press section, reslushed and re-made into handsheets.

vacuum level of the dry runnability element and the residual tension has correlation. The higher the residual tension, the lower the vacuum is needed. So that is one indirect result.

Torbjörn Wahlström

I think it is very direct, it is a very interesting result. How is the residual tension measured?

Elias Retulainen

That is measured from samples taken after the wet press section of the pilot machine. It has been published in Kouko, J., Kekko, P., Liimatainen, H., Saari, T., Kurki, M., Wet runnability of fibre furnish of magazine papers, Paperi ja Puu 88(3): 2006, 169–174.

Petri Mäkelä Innventia

Thank you for a nice presentation, Elias. I have one question. When a material is subjected to a step in load or deformation, it responds with a transient mechanical behaviour. This transient dies away with time. The length of the transient is related to the required time for reaching the applied load or deformation. For this reason, there is a rule of thumb in stress relaxation and creep testing, which states that reliable material data can be collected after a time period that is 10 times longer than the time required to reach the prescribed load or deformation in the test. In Figure 5, you show results for initial tension and residual tension, where the strain rates 1, 10, 100, and 1000 %/s, respectively, were used. The time to reach the prescribed strain of 2 % consequently was 2, 0.2, 0.02, or 0.002 s, respectively. But as I understand it, you evaluated the residual tension 0.475 s after the prescribed magnitude of strain was reached, irrespective of the strain rate used. So I wonder have you compared the residual tension for the different strain rates after longer times, for example after 20 s? If so, do you still see a reduction in residual tension with increased strain rate after longer times?

Elias Retulainen

As far as I know we have not, but it does not sound relevant from our point of view. If you really want to simulate and measure the relaxation that is happening in a fast paper machine, why wait 20 seconds when the paper is already drying? Recent results of Pasi Kekko have shown that after fast straining (1000%/s) of wet paper, the stable log-linear relaxation phase starts very quickly and earlier than with air-dry paper. The delay with wet paper is about 20 ms.

Petri Mäkelä

It might not be relevant for what happens on a fast paper machine, but it is from a fundamental point of view. It appears that you have evaluated the residual tension for the slowest strain rates in the transient region, while the residual tension for the fastest strain rates are evaluated after the transient has died away. The question is whether this may explain that you observe a residual tension that decreases with increased strain rate? Maybe you should consider making some controlled laboratory experiments where the available time for drying is kept constant and where the residual tension is evaluated after sufficiently long times, in order to make residual tensions for different strain rates fairly comparable? Finally, I would like to add that a strain rate of 1%/s, which you have used in your experiments, is not relevant for what happens on a fast paper machine.

Discussion

Elias Retulainen

Okay, thank you for the comment.

Eva Larsson Lyckeby Starch

On the last slide (figure 12 in the paper in the proceedings, ed.) with the dialdehyde starch compared to the reference and the cationic starch at different dry solids content. How much do you think that differences in dry content influenced the runnability compared to what you gain in the residual tension? You have approximately 55% solids for the dialdehyde starch sample but you are up to 57% and 59% for no starch and commercial starch, respectively. The dry solid content has a very big influence on the runnability.

Elias Retulainen

Yes, the dry solid content is important, but in this experiment I would not look at the dry solid content so closely. I am not sure if this is a relevant reduction, especially as the chemicals were added by spray application before wet pressing.

Eva Larsson

It is relevant. If you have a cationic starch you can have a higher dewatering rate and you get higher solids, and if you have a dialdehyde starch it is more problematic to dewater it, so the figures themselves are relevant.

Elias Retulainen

Okay, I have not looked at it from that point of view. If you compare the low wet pressing pressure cases, the cationic starch point should be on a little higher level?

Eva Larsson

Yes. Of course, if you have retention agent, they will be more similar. But I think the effect after the press section before going into the dryer section will be like that. So that is a drawback when you use dialdehyde starch.

I also noticed it when you had deionized water compared to the other things (figure 10 in the paper in the proceedings, ed.). Even if you have higher residual tension, you lose some dry strength, especially with surfactants, because that will also influence the bonds.

Elias Retulainen

Okay! Thank you for this comment.

Gary Baum PaperFuture Technologies (from the chair)

I have just one comment, Elias. In an earlier slide you showed residual tension going down with increasing strain rate. Do you have any idea why that might have been, or was just within the experimental error?

Elias Retulainen

There is definitely something real behind this, but what is the explanation for that? I think that the fast straining rate somehow cuases different kinds of stress patterns in the web that somehow favour faster relaxation.