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THE IMPACT OF PAPER DEFECTS ON PAPER STRENGTH REQUIREMENTS

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ABSTRACT

In this paper, the impacts of defect type, shape and position on the runnability related strength properties are discussed. As an example, a wood-containing coating base paper is studied. A typical break position on coated mechanical pulp-containing magazine paper production is the first coating unit on a blade coater. There the wetted paper web has to be strong enough and as uniform as possible in order to bear all the stresses under and after the blade.

Very few systematic runnability studies in coated paper production have been reported. Only small step changes and no breaks are tolerated in commercial paper production. Consequently, opinions about relevant test methods for predicting paper runnability have been based on indirect studies. To bypass this obstacle, pilot runnability tests have been included in this study. These results are compared to laboratory sheet studies.

Paper does not break because of its low average apparent strength, but because of a defect in the web of sufficient size, befitting shape, position and orientation. The type of defect is decisive on how reinforcement pulp must be treated and how much of it is needed. Defect type is also important in choosing

proper measurement methods in order to predict the endurance of the paper web. Pilot coating trials were used to test base papers where two clearly different types of defects were intentionally made. Defect types were hole and plain cut. These were made at constant intervals into the web. During the coating trial of such defected web, the tension over the coating unit at the moment of a break was considered an indication of the actual strength of paper. In the results, one could clearly distinguish between different behaviour patterns with different defect shapes. Differences were noticed, e.g., as a different maximum tension at a break, and as a different behaviour under the coating blade.

Additionally, handsheet studies using reinforcement pulps refined differently were carried out in order to evaluate their impact on tensile strength of notched samples. Holes and cuts were introduced into the test specimen. The effect of the addition of reinforcement pulp was dependent on the type of mechanical pulp used and on the level of refining of reinforcement pulp so that the effects obtained with notched samples were not predictable while testing undamaged sheets only. FEM (Finite Element Method) analyses simulating stress concentrations around defects gave compatible results with those from pilot coatings and improved our understanding why cut-type defects are so harmful.

A fibre network study was included in order to study the effect of different fibre networks on paper strength. The importance of chemical pulp beating and interaction between mechanical and chemical pulp was emphasized in these experiments.

The results seemed to be compatible with practical experiences in actual paper manufacturing processes, where paper is coated. The measurements based on the work needed to propagate a cut are not satisfactory in all respects. Fracture toughness may overestimate the benefits of chemical pulp addition and underestimate the benefit of chemical pulp beating. However, fracture toughness is clearly more suitable for predicting coating base paper runnability than the conventional (Elmendorf) tear strength measurement. Tear strength development of paper suggests that almost no beating of chemical pulp is needed, which is clearly not in accordance to our results. Instead, apparent tensile strength tests made on paper specimen with slits in it is a relatively well suited method for predicting the runnability of the base sheet in coating.

INTRODUCTION

Breaks that take place in paper production and excessive use of reinforcement pulp cause huge expenses in manufacturing of wood-containing printing papers. In the research, runnability has been most often approached from two angles. One is the study of mechanisms of various strength measurements, and the comparison of these to sheet fracture mechanisms produced in the laboratory in order to simulate actual break situations. Another is the comparison of paper strength properties and break statistics in printing processes. However, the opinions about the methods suitable to predict the runnability on paper or coating machines have been incoherent and even contradictory.

The runnability prediction of paper webs in newsprint manufacturing as well as the paper runnability on printers has been studied quite extensively. Here, the value of fracture toughness has been indicated by, e.g., Seth [1,2]. Åström et al. suggested that runnability on paper machines and printing presses are best characterized by using the fracture toughness method. If that characterization method is accepted, one can then notice that additional refining of chemical pulp improves the runnability [3]. Fellers et al. have concluded that runnability of paper in printing presses can only be evaluated with fracture toughness, not with other standardised paper tests. They also noticed that when defect size was increased, critical force and critical elongation decreased dramatically, and that straight, beaten fibres gave best critical force, while curly fibres gave higher critical elongation [4].

Influence of coating base paper properties on runnability has not often been a subject of systematic research. Palsanen, in his work based on production scale data, concluded that tensile strength and burst strength explained quite well the runnability in a separate coating machine in a LWC (Light Weight Coated paper) line. Tear strength again had no influence on runnability at all [5].

Among researchers of newsprint and other uncoated papers, their common opinion is that in-plane types of rupture tests as fracture toughness are clearly better suited to runnability prediction of (sufficiently dried) paper than out of plane tests as the Elmendorf tear test. However, in LWC base paper production, the Elmendorf tear test is still widely used and relied as a test for predicting the need of the amount of reinforcement pulp and the refining of that [6]. However, there is a potential danger that an excessive amount of reinforcement pulp is used, and unnecessary breaks occur because of unsuitable test methods.

The main reason for causing the lack of understanding of proper test methods for predicting the coating base paper runnability is that systematic runnability studies in real paper production have been rare because only small step changes and no breaks are tolerated in the commercial paper production. To by-pass this obstacle, pilot plant runnability tests simulating real production situations have been introduced in this study. The results were then compared to some laboratory sheet studies. In both, pilot paper and laboratory sheets, the impacts of defects were studied.

In the LWC base paper, the proportion of reinforcement pulp is relatively high. That is why the thorough understanding of reinforcement mechanisms is needed. Long and slender fibres of chemical pulp are preferable, fibres should contain fibrils that stay on the fibres and sufficient amount of fines are needed [6]. But how can good interaction between fibres of chemical pulp and mechanical pulp be accomplished? If a synergistic effect is achieved, the need for reinforcement pulp is lower. Unfortunately, this is not always the case and chemical pulp and mechanical pulp in a sheet of paper gives the strength that is only the sum of the strengths of the pulps, thus indicating the behaviour of two separate or almost separate networks [7]. Here again, the relevant measurement method is crucial in the determination of the best preparation of furnish fractions.

The strength of undamaged paper is clearly above the strength that is required during paper manufacturing or printing processes. Holes and other defects in the paper web, however, drastically decrease the overall strength of the paper web. Structural homogeneity in the plane and in the thickness direction is decisive to good runnability. Good formation improves the strength of the web. Sufficient orientation of fibre in the direction of the stress is advantageous. Holes, cuts, shives, fibre clumps and slime spots make the web locally substantially weaker than the homogeneous areas of the web. This calls for good reinforcement pulp, containing strong, long and slender fibres that can be easily fibrillised. However, because of higher costs and quality reasons like poorer opacity and higher porosity the addition of chemical pulp needs to be kept as low as possible.

The hypothesis of this work is that paper does not break because of its low average apparent strength but because of a defect in the web of sufficient size, befitting shape, position and orientation and that the type of defect is decisive on how reinforcement pulp must be treated and how much of it is needed. Consequently, the presence of a defect in testing a paper specimen and the type of defect anticipated is important in choosing the proper measurement method in order to predict the endurance of the paper web.

In this paper, the impacts of defect type, shape and position on the runnability-related strength properties are studied. As an example, a wood-containing coating base paper is studied on a pilot scale coating. A typical break position on a LWC-production line is the first coating unit on a blade coater. There, the wetted paper web has to be strong enough and as uniform as possible in order to bear all the stresses under and after the blade. The wetting goes on after the blade and then the dimensions of the web change, which also in some cases, affect the runnability. Additionally, the results of laboratory testing series are discussed. The effects of holes and cuts on the strength of paper and on the reinforcement capability of chemical pulp was also studied. Some preliminary studies were also made to test the hypothesis that a continuous minimum backbone sheet structure of reinforcement pulp fibres is needed before the reinforcement takes place. The effect of the type of damage was studied also by FEM simulations in order to better understand the results obtained in experiments mentioned above.

EXPERIMENTAL

Pilot coatings

Pilot coating trials were used to test base papers where two clearly different types of defects were intentionally made. Defect types were: hole and plain cut. They were placed at constant intervals into the web. When coating such a web in the presence of defects, the tension of the web was constantly increased until the web broke. Tension over the coating unit at the moment of break was recorded, and it was considered an indication of the actual strength of paper.

Pilot coater used at Tampere University of Technology, Paper Converting Department:

- Blade coating with roll application prior to the levelling of the coating colour with the blade.
- Aqueous mineral coating colour was used, coat weight 12 g/m^2 on one side.
- Coating colour was taken from coating colour circulation of a commercial on-line LWC machine.
- Web width was 350 mm and basis weight of paper 38 g/m^2, NBSK pulp content 37%.
- Speed was 2 m/s.

Defects in coating trials were as follows:

- Holes in the middle of the web, diameter 0, 10, 15, 20, 25, 30, 35 mm.
- CD cut in the middle of the web, length 0, 10, 15, 20, 25, 30 mm.

Studies with damaged laboratory sheets

In the handsheet studies, reinforcement pulps refined in different ways were used. These were carried out in order to evaluate the impact of refining on tensile strength of notched samples. In the sheets, holes and cuts were produced; holes and cuts of different sizes in the middle of the sheet, and cuts in the edge. Defects introduced in these handsheet experiments were: holes in the middle of sample, diameter 10 and 20 mm, cuts of 10 mm and 20 mm in the middle of and on the edge of sample in cross direction to straining. Sample width was 50 mm. An automated sheet moulder was used to make the sheets. Sheet pressing pressure was 414 kPa.

The pulps used were: TMP (Thermo Mechanical Pulp), CSF 50 ml, average fibre length 1.50 mm, GW (Groundwood) pulp CSF 50 ml, average fibre length 0.80 mm, less beaten chemical pulp CSF 590 ml, average fibre length 2.21 mm and more beaten chemical pulp CSF 450 ml, average fibre length 2.33 mm.

Chemical pulps were beaten in paper mill lines. The CSF 450 ml NBSK pulp was 100% reinforcement pine kraft of mill A and the CSF 590 ml NBSK pulp was a blend of 50% reinforcement pine kraft of mill A and 50% reinforcement pine kraft of mill B. Differences between reinforcement pulps A and B were nominal before refining, and the refiners were similar in both lines. The difference was in the amount of refining energy used.

Chemical pulp content in handsheets was 0, 25, 35, 45 and 100% and basis weight was 40 g/m^2. Measurements were done with a laboratory tensile strength tester.

Further, a handsheet study was made in order to verify the results of previous tests. TMP and GW were also used in these experiments and reinforcement pulp from kraft mill A was used. This time, chemical pulp was beaten to freeness levels of 250 ml and 450 ml. Also unbeaten chemical pulp of freeness 720 ml was used. The chemical pulp content in handsheets was from 0 to 40%. Also, blends of these separately beaten chemical pulps were used (see Figures 8 and 9).

Studies of fibre networks in laboratory sheets

A handsheet series was carried out in order to study the interaction between chemical pulp and mechanical pulp. Three series of handsheets were made. First, wet sheets with chemical fibre network and mechanical fibre network were couched together by wet pressing and secondly, series of sheets where two wet sheets of similar fibre composition were pressed together. Thirdly, standard laboratory sheets were made of pulp mixtures with similar fibre compositions. Strength properties of these sheets were measured to study whether chemical fibre network reinforces differently as a solid network joined to mechanical pulp network compared to the situation where chemical and mechanical pulp fibres are mixed together.

Two types of mechanical pulp were used. These were typical spruce TMP for magazine papers, CSF 57 ml, (length weighted) average fibre length 1.57 mm and newsprint PGW (spruce) pulp, CSF 108 ml, average fibre length 0.88 mm. The newsprint PGW represented an older type of mechanical pulp formerly used in mechanical pulp-containing magazine papers.

Chemical pulp used as a reinforcement pulp was beaten to two freeness levels using a Valley-laboratory beater. In addition to these, PFI beater was used to simulate medium/high consistency beating to give chemical pulp a higher elongation potential. Freeness levels of Valley beaten NBSKP were 630 ml and 450 ml, average fibre length 2.40 and 2.21, respectively. Freeness of PFI beaten NBSKP was after beating 500 ml and average fibre length 2.32 mm. The basis weight of handsheets was 60 g/m ^{2}. The amounts of chemical pulp added were 5, 9, 15 and 21 g/m ^{2}.

RESULTS

Pilot studies

In the results one could clearly distinguish between different behaviour patterns with different defect shapes. Differences were noticed, e.g., as different maximum tensions at a break and different behaviours under the coating blade. We also noticed that the breaks under the blade were related to the sizes of wrinkles caused by the defect. This is typical for blade coating of light weight papers.

The effect of hole-type defects on breaking tension on blade coating is shown in Figure 1. Breaking tension decreased up to 40% when holes were present in the base paper. In this case, hole diameter was 17 mm and width of base paper 550 mm.

The effect of defect size and shape on breaking tension decline is shown in Figure 2. Holes and cross-direction cuts of different sizes in the middle of the web were tested. First of all, a transition level from undamaged to damaged web was seen with both defect types. When the defect size increased, the effect of cross-direction cuts and holes was slightly different. In the beginning, cross-direction cuts decreased the breaking tension level clearly faster than holes did. However, if the size of defects was big enough, the effect of defect shape seemed to decrease, or vanish.

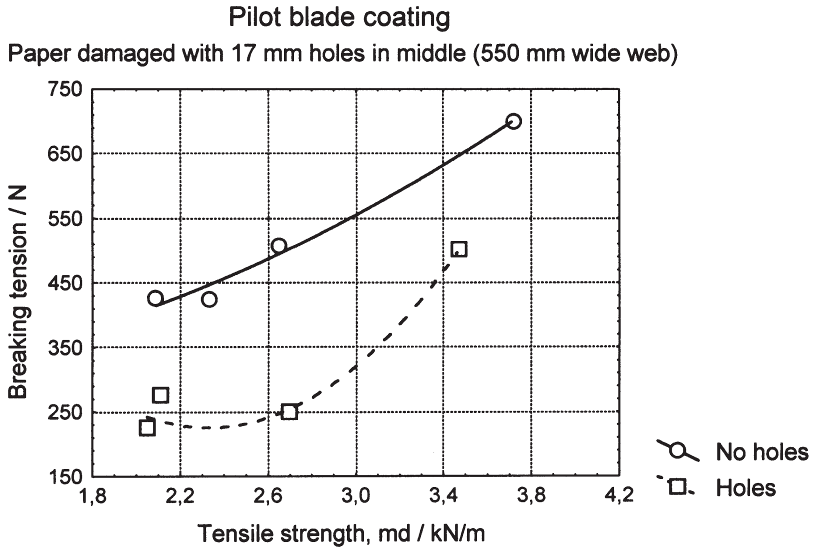

Figure 1 An example of the effect of defects on breaking tension on a pilot coating machine with different types of base papers.

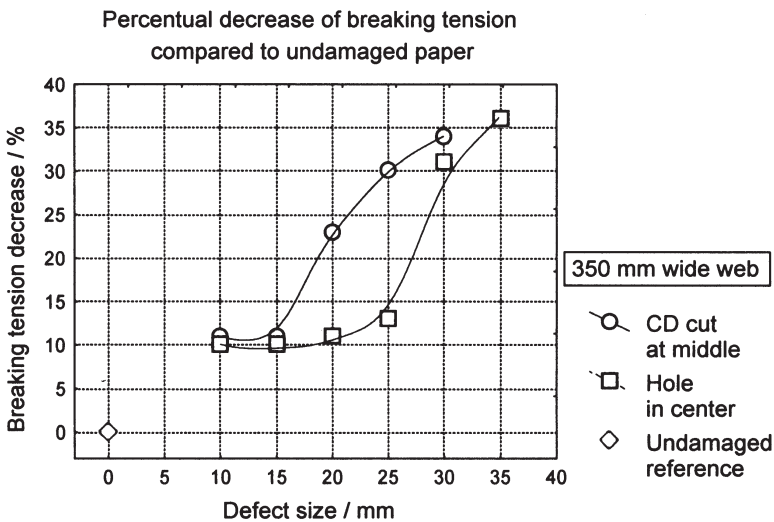

Figure 2 An example of the effect of defect shape and size on tension at brake in blade coating.

Handsheet studies with damaged handsheets

In the handsheet studies, it was noticed that the effect of reinforcement pulp addition was dependent on the type of mechanical pulp used and the level of beating of reinforcement pulp. The effects obtained with notched samples were not predictable from the testing of undamaged sheets only.

In the following Figures 3 to 9, the effect of chemical pulp beating and addition level on paper strength is presented. Figures are given separately for each defect type.

Results of TMP based sheets are shown in Figures 3 and 4. Following conclusions can be drawn:

– Response of paper strength in the presence of defects depended highly on chemical pulp beating. The bigger the defects, the more important the beating was.
– The major difference between defects was their shape. Hole-type defects decreased the strength clearly less than cross direction cut-type of defects. The position of the defect was of lesser importance in these comparisons.

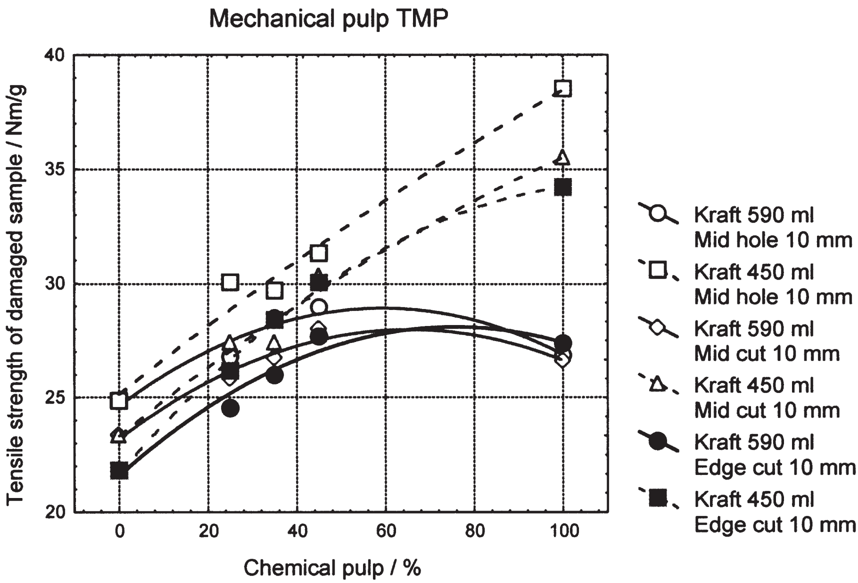

Figure 3 The effect of defect shape and size on paper strength at various chemical pulp (bleached soft wood/pine kraft) addition levels. Mechanical pulp is TMP. Specimen width 50 mm.

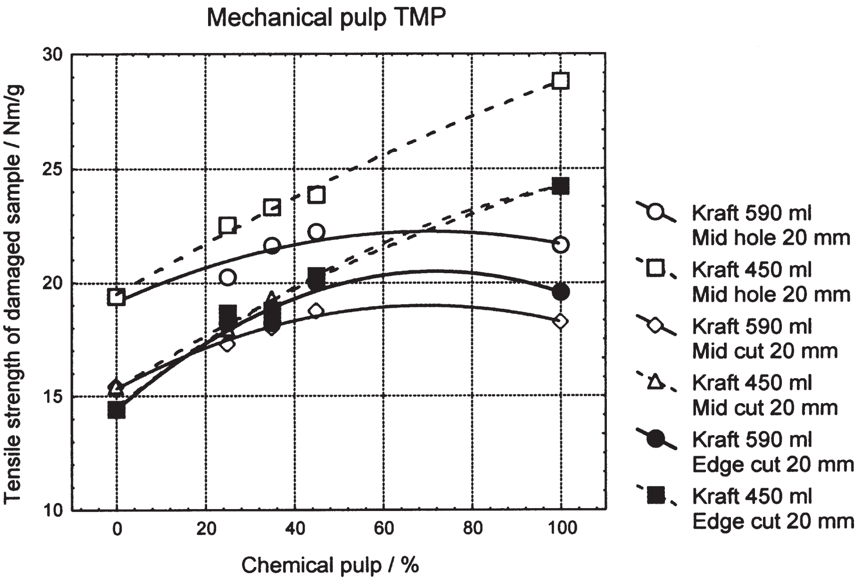

Figure 4 The effect of defect shape and size on paper strength at various chemical pulp (bleached soft wood/pine kraft) addition levels. Mechanical pulp is TMP. Specimen width 50 mm.

Regarding GW based sheets, the following conclusions can be drawn (Figures 5 and 6):

- The response of paper strength in the presence of defects depended highly on chemical pulp beating, but kraft percentage also had a significant impact on paper strength.
- The major difference between defects was their shape. Hole-type defects decreased strength clearly less than cross direction cut type of defects. The position of the defect was of lesser importance in these comparisons.

Figures 3 to 6 are combined together to form Figure 7 in order to give a clear comparison also between TMP and GW.

The main differences between the behaviour of TMP and that of GW were as follows (Figure 7):

- Strength level in the presence of defects was clearly higher in the case of TMP compared to GW at same NBSKP addition level.

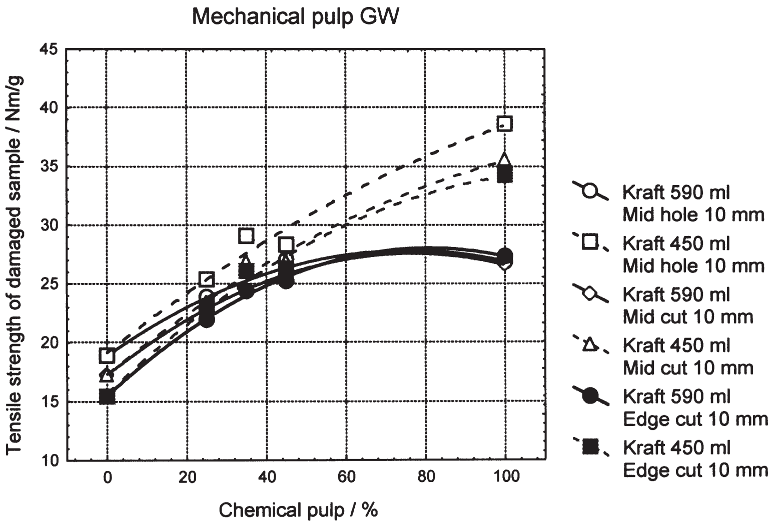

Figure 5 The effect of defect shape and size on paper strength at various chemical pulp (bleached soft wood/pine kraft) addition levels. Mechanical pulp is GW. Specimen width 50 mm.

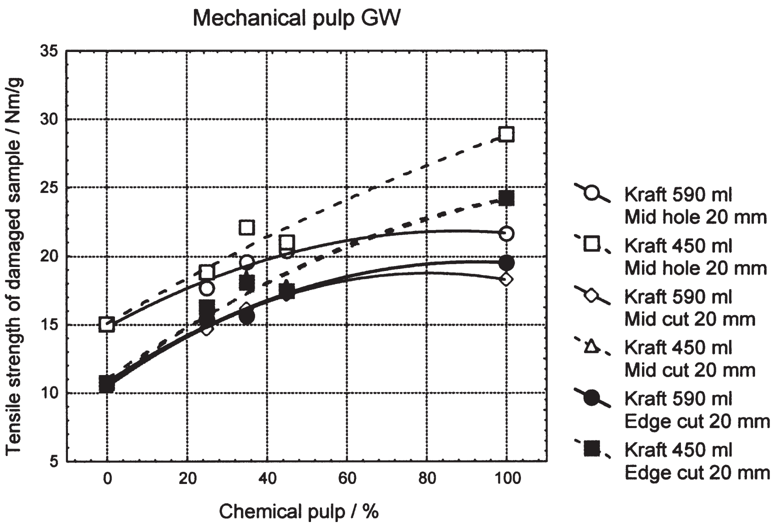

Figure 6 The effect of defect shape and size on paper strength at various chemical pulp (bleached soft wood/pine kraft) addition levels. Mechanical pulp is GW. Specimen width 50 mm.

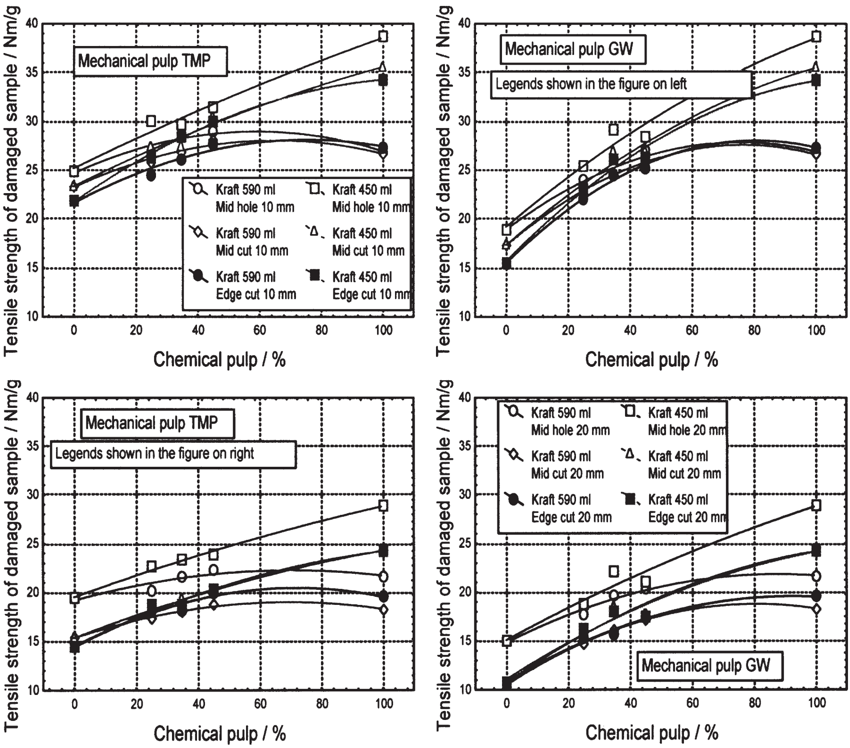

Figure 7 The effect of defect shape and defect size on paper strength at various chemical (bleached soft wood/pine kraft) pulp addition levels. TMP (left) and GW based sheets compared.

– GW-based sheets showed a faster strength increase as a function of NBSKP addition than TMP based sheets.

In order to shed more light on the impact of reinforcement pulp beating on a measure, which we assume to well predict base paper runnability and to possibly confirm the results presented above, an additional laboratory study was made. The NBSKP was refined to three different beating levels. Each level of beaten NBSKP were mixed with TMP and PGW to form furnishes with chemical pulp contents from 0% to 40%. Tensile strength of notched samples was measured.

Measurements were done with 50 mm wide samples with 15 mm cut in the middle in cross direction to straining with L&W fracture toughness device. Tensile strength of these samples is later regarded as "apparent tensile strength".

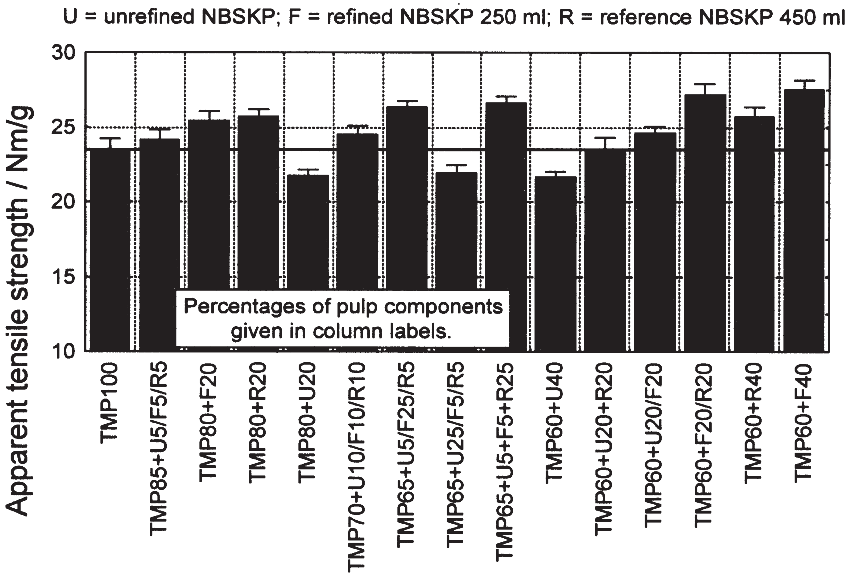

Figure 8 The effect of chemical pulp beating and content on tensile strength of damaged TMP based paper. Values in column labels after each abbreviation of pulp name give the percentage shares of respective components.

In the case of TMP-based sheets, the degree of beating of the reinforcement pulp clearly had a greater effect on the strength of damaged sheets than did the proportion of reinforcement pulp. On the other hand, in the case of GW sheets, the addition level of the reinforcement pulp had more effect on damaged sheet strength than the degree of beating.

Network study

Studies of Mohlin and Wennberg [7] and Kazi and Kortschot [8] have indicated that mechanical and chemical pulp may form separate networks in the sheet and bonding between fibres of mechanical and chemical pulp is less effective than interfibre bonding of mechanical pulps. Our intention was to find out how much, and to which direction, does the interfibre bonding in the normal sheet deviate of the bonding obtained, when the sheet literally is composed of two separate layers, one of chemical pulp and another of mechanical pulp. This was done in laboratory scale using magazine TMP produced by using up-to-date technology and for comparison purposes, rougher PGW, together with reinforcement pulps refined to various CSF levels.

Based on pilot coating results and laboratory study results with a damaged specimen, we have concluded that refining of reinforcement pulp is beneficial and consequently the focus here is on the measurements of conventional and apparent tensile strength, and elongation at break.

When we compare sheets made separately layering chemical and mechanical pulp, with mixed pulp forming two-layered sheets, both mechanical pulps behaved similarly. Separately layered sheets showed lower tensile strength. This suggests that in sheets of mixed pulps there are effective bonds between fibres of chemical and mechanical pulp.

Even more so because the strength level in sheets made of pulp mixtures was higher than the linear sum of component strengths. In conventional tensile strength measurement there was an exception, namely that the PGW/chemical pulp mixture followed the pattern of layered sheets. In apparent tensile strength measurements, however, all mixture sheets, one-layer and

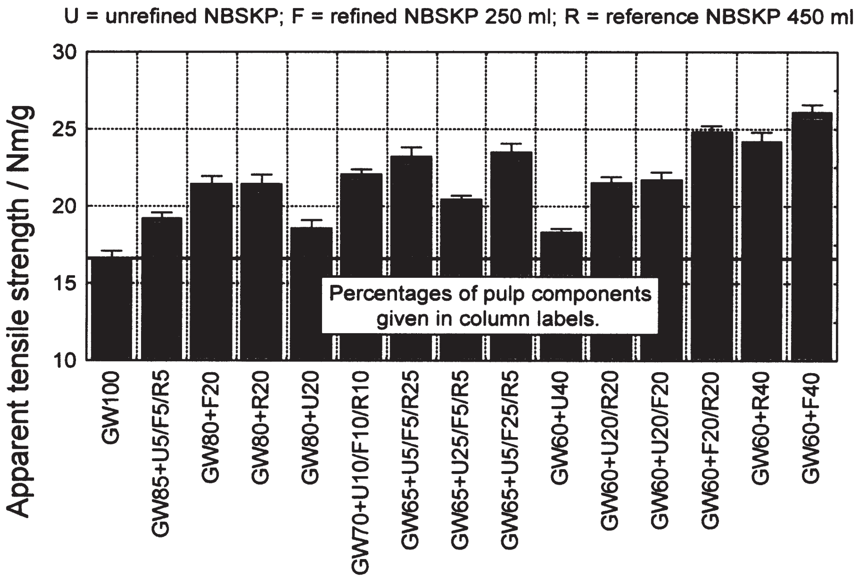

Figure 9 The effect of chemical pulp refining and content on strength of damaged GW based paper. Values in column labels after each abbreviation of pulp name give the percentage shares of respective components.

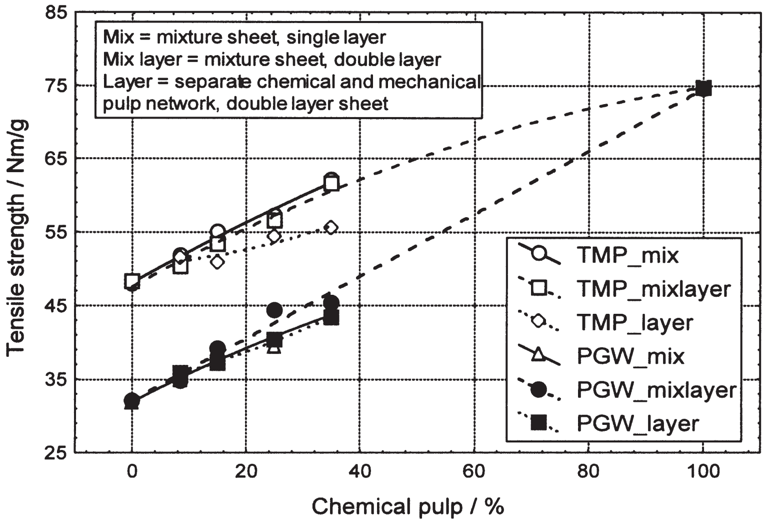

Figure 10 Tensile strength of single and double layered laboratory sheets. Chemical pulp was beaten in laboratory (Valley) to CSF 630 ml.

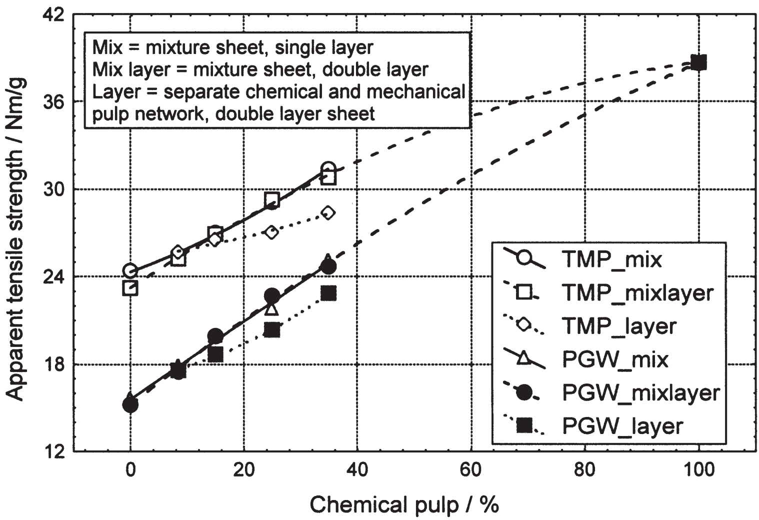

Figure 11 Apparent tensile strength of single and double layered laboratory sheets. Chemical pulp was beaten in laboratory (Valley) to CSF 630 ml.

two-layer, showed higher values than sheets of separately layered fibre components.

Elongation at break was highest in conventional sheet with mixed pulp components. At the chemical pulp level of about 20% and above, the sheets with separately formed fibre components showed lower elongation than sheets made of mixed pulps, made normally or in two layers. This result also suggests that there indeed is a clear interaction between fibres of chemical and mechanical pulps. This was more pronounced in TMP based sheets. The freeness level of TMP was clearly lower than that of PGW which at least partly explains the better bonding, also with fibres of chemical pulp.

In Table 1, from a runnability point of view, important strength measures are compared. These are average values when chemical pulp was beaten to three different freeness levels so the results are more generic in that respect. However, only one addition level of chemical pulp is included, namely 35%.

Table 1 Tensile strength, apparent tensile strength and elongation at break of 60 g/m^2 laboratory sheets. Chemical pulp dosage was 35%. Average values of sheets with three different chemical pulp freeness level (630 ml, 500 ml and 450 ml).

	TMP Reference, mixed fibres	TMP Layered com- ponents	TMP Mixed fibres, layered sheet	PGW Reference, mixed fibres	PGW Layered com- ponents	PGW Mixed fibres, layered sheet
Tensile strength/ Nm/g	63.8	59.1	63	49.1	47.3	46.2
Apparent tensile strength/ Nm/g	32	30	31.2	26.1	23.7	25.2
Elongation at break,%	2.9	2.68	2.98	2.38	2.38	2.56

These results support those obtained at various chemical pulp dosages. In the case of TMP, mixed fibre sheets, single and double layered, showed clearly higher strength values than sheets with separately layered components. In the case of PGW, the results are not as clear, but quite similar, especially when apparent tensile strength is concerned.

As an intermediate conclusion one may state that the network study results

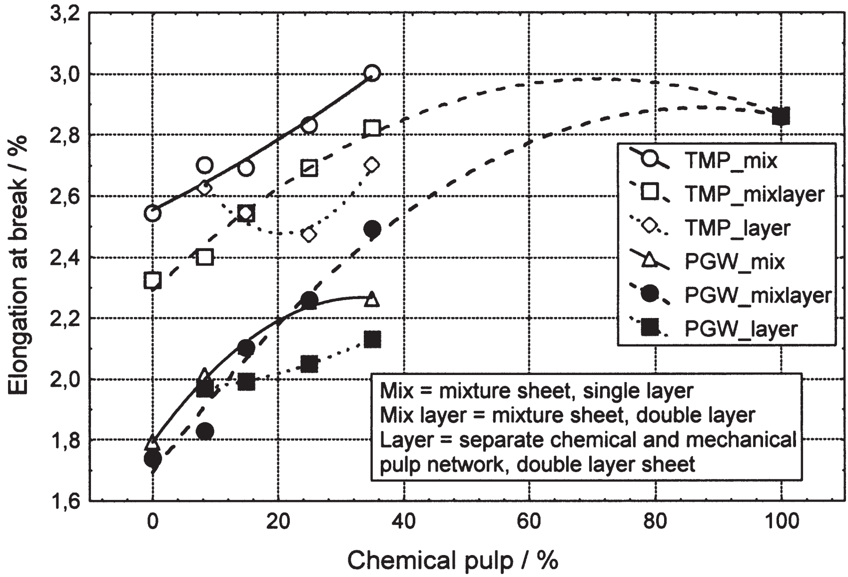

Figure 12 Elongation at break of single and double layered laboratory sheets. Chemical pulp was beaten in laboratory (Valley) to CSF 630 ml.

obtained here do not seem to support a view that the softwood chemical pulp fibres reinforce the mechanical pulp containing sheet structure through a network of chemical pulp alone.

Analyses of stress concentration by means of finite element method (FEM) – simulations

The simulations were carried out in order to evaluate the load distribution in the web in the presence of defects in an open draw. Different behaviour patterns might be able to explain whether different types of defects need different types of paper strengths. Web width in these simulations was 350 mm.

The cases simulated were:

1. a cross direction cut in the middle;
2. a cut in 45° angle in the middle of the web;
3. a hole in the middle of the web.

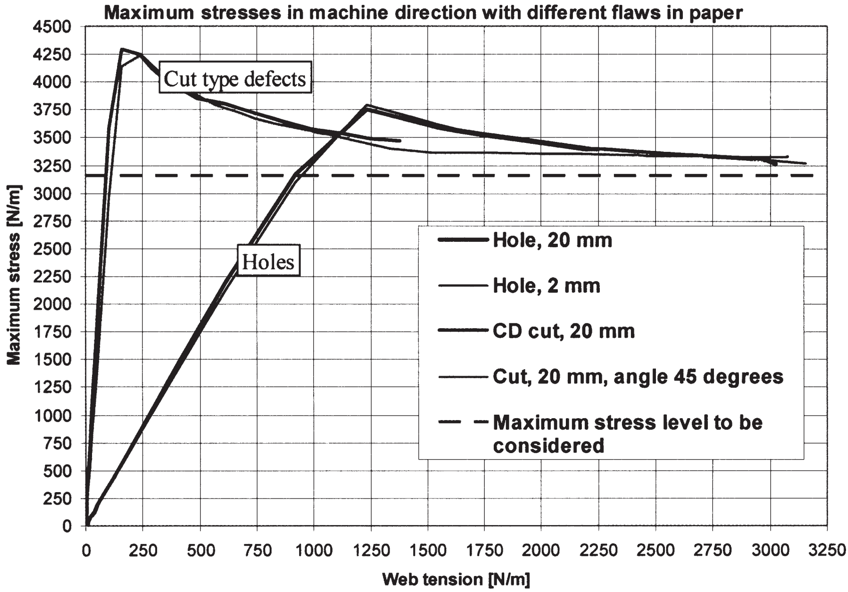

Figure 13 The dependency between web tension and maximum stress around defect.

Figure 13 presents the maximum stress of a paper web in an open draw as web tension was increased. Stress concentrations in Figures 14, 15, 16 and 17 were calculated at the moment when maximum stress around the defect reached the level of actual strength of the paper web.

In the case of cut-type defects, the maximum stress around the defect increased very rapidly when compared to hole-type defects. Based on the results obtained, the maximum stress reached the actual strength of paper in the case of cuts in almost one tenth of the tension of that in the case of holes. The effect of hole size was insignificant within the interval studied. Placing the cut-type defect on an angle of 45° also did not have any significant effect when compared to a cut in cross-direction.

Only a marginally higher maximum stress was seen in the case of a 20 mm hole as in case of a 2 mm hole at web tension of 917 N/m (Figures 17 and 18). In practice this means that maximum stress reaches the level of actual strength of paper at slightly lower tension in the case of 20 mm hole than in the case of 2 mm hole. Also stress concentration areas were very much alike with slack areas in the machine direction before and after the hole.

Figures 16 and 17 show the stress concentrations around a cross direction

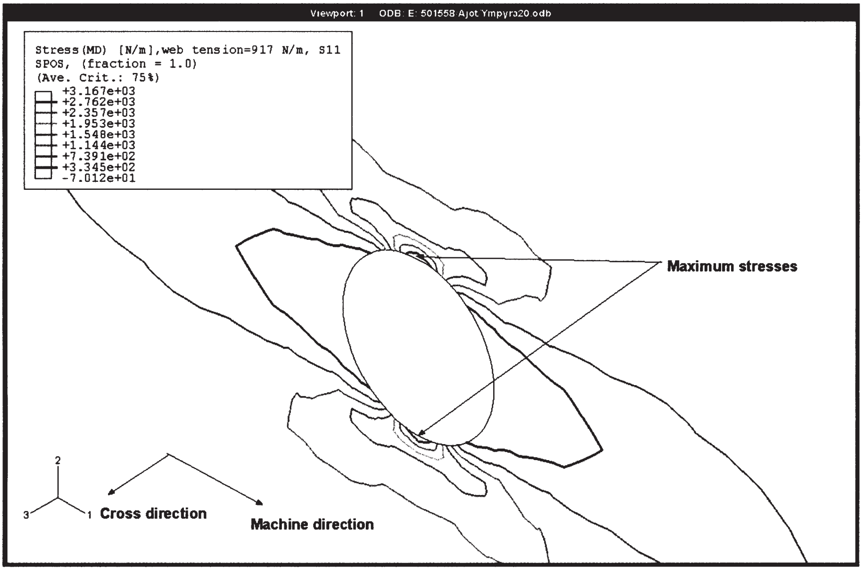

Figure 14 The dependency between web tension and maximum stress around a hole.

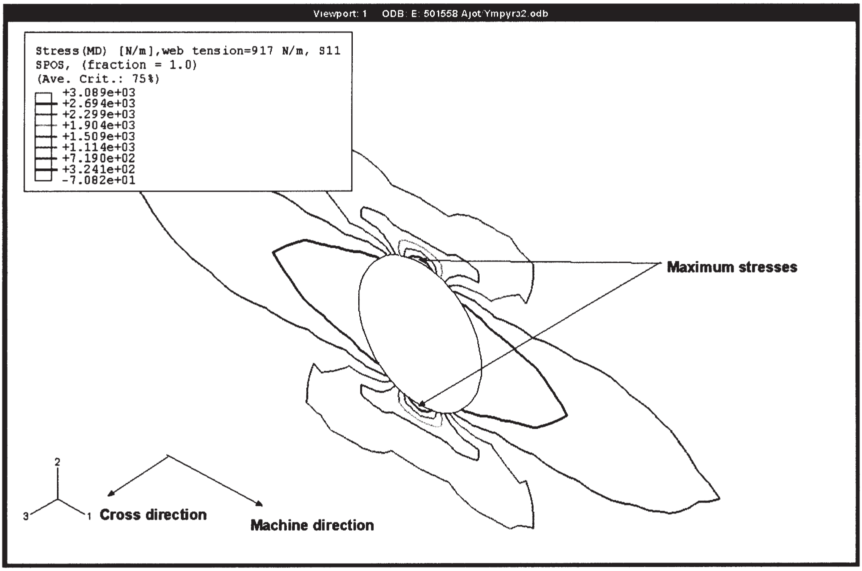

Figure 15 The dependency between web tension and maximum stress around a hole.

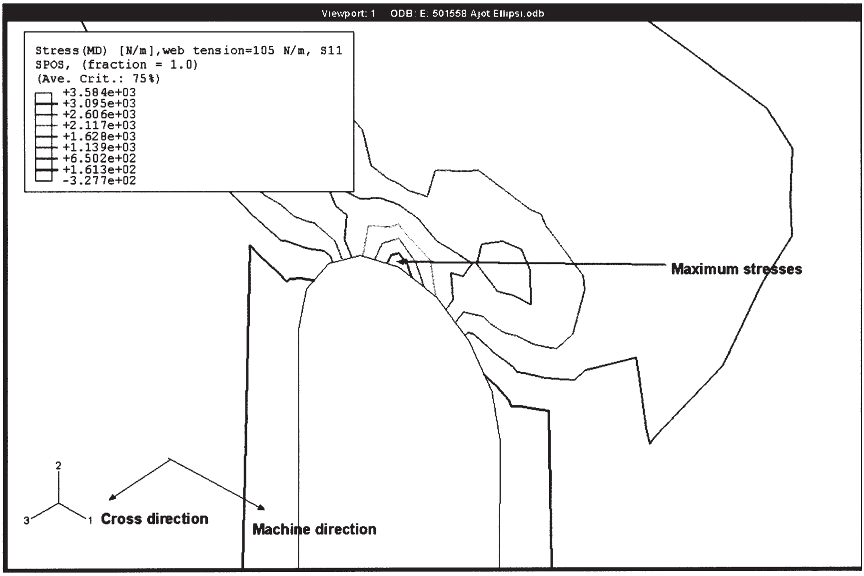

Figure 16 The dependency between web tension and maximum stress around a cut.

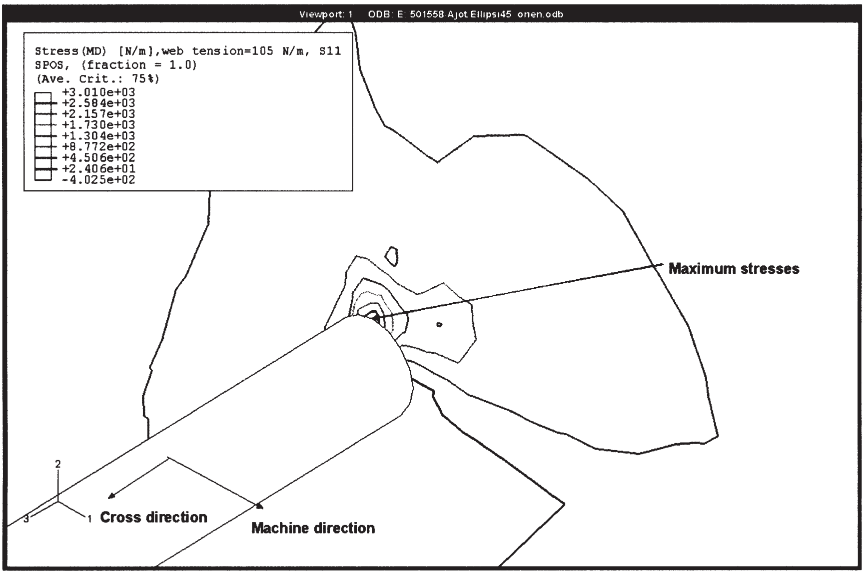

Figure 17 The dependency between web tension and maximum stress around a cut.

cut and a cut on a 45° angle compared to a cut in cross direction at web tension of 105 N/m. A lower maximum stress was noticed in the case of the cut on a 45 degree angle. In practice this means that maximum stress reaches the level of actual strength of paper at slightly lower tension in the case of pure cross direction cut than in the case of cut of same length in 45° angle.

Comparison between strength property measurements

Measured strength properties and percentage changes of them when chemical pulp addition was changed, are presented in Tables 2 and 3. Results

Table 2 The effect of kraft addition on strength properties in the case of TMP base sheet.

Chemical pulp	NBSKP 590 ml 25%	NBSKP 590 ml 45%	NBSKP addition 25% –> 45%	NBSKP 450 ml 25%	NBSKP 450 ml 45%	25% –> 45%
Mechanical pulp type	*TMP*	*TMP*	*Change in %*	*TMP*	*TMP*	*Change in %*
Kraft pulp percentage/%	25.0	45.0	80	25	45	80
Tensile index/Nm/g	43.7	45.1	3	47.3	51.5	9
Tensile energy absorption/J/kg	770.0	870.0	13	850.0	1030.0	21
Tearing strength/mNm^2/g	6.7	9.2	37	6.4	8.3	30
Burst index/kPam^2/g	2.8	3.0	8	3.3	3.9	17
FS-200 fibre length	1.7	1.9	10	1.7	1.9	11
Fracture toughness/Jm/kg	12.3	15.4	25	11.7	14.9	27
Apparent tensile strength/Nm/g	23.2	24.7	6	24.3	26.8	10
Tensile index, mid hole 10 mm/Nm/g	27.2	28.5	5	28.7	31.7	10
Tensile index, mid hole 20 mm/Nm/g	20.8	21.7	4	22.3	24.0	8
Tensile index, mid cut 10 mm/Nm/g	26.0	27.4	5	27.0	29.7	10
Tensile index, mid cut 20 mm/Nm/g	17.2	18.5	8	18.1	20.1	11
Tensile index, edge cut 10 mm/Nm/g	25.1	27.0	8	26.6	29.8	12
Tensile index, edge cut 20 mm/Nm/g	17.8	19.5	10	18	20.2	12

Table 3 The effect of kraft addition on strength properties in the case of GW base sheet.

Chemical pulp	NBSKP 590 ml 25%	NBSKP 590 ml 45%	NBSKP addition 25% –> 45%	NBSKP 450 ml 25%	NBSKP 450 ml 45%	25% –> 45%
Mechanical pulp type	*GW*	*GW*	*Change in %*	*GW*	*GW*	*Change in %*
Kraft pulp percentage/%	25.0	45.0	80	25.0	45.0	80
Tensile index/Nm/g	38.2	41.0	7	40.9	46.3	13
Tensile energy absorbtion/J/kg	620.0	770.0	24	645.0	830.0	29
Tearing strength/mNm^2/g	6.1	8.8	44	5.4	7.5	39
Burst index/kPam^2/g	2.3	2.7	17	2.8	3.5	25
FS-200 fibre length	1.1	1.4	26	1.1	1.4	28
Fracture toughness/Jm/kg	8.6	12.1	41	8.6	12.5	45
Apparent tensile strength/Nm/g	19.4	22.5	16	21.0	25.4	21
Tensile index, mid hole 10 mm/Nm/g	23.7	26.3	11	25.2	29.7	18
Tensile index, mid hole 20 mm/Nm/g	18.2	20.1	10	19.1	22.1	16
Tensile index, mid cut 10 mm/Nm/g	22.8	25.7	13	23.4	27.7	18
Tensile index, mid cut 20 mm/Nm/g	14.7	17.0	16	15.5	18.8	21
Tensile index, edge cut 10 mm/Nm/g	22.0	25.6	16	22.8	27.3	20
Tensile index, edge cut 20 mm/Nm/g	15	17.3	15	15.7	18.8	20

clearly indicate that when the chemical pulp addition level and the beating level in base paper were changed, the dependency is significantly different depending on which strength property is measured. This dependency is also somewhat different if mechanical pulp is TMP instead of GW. Depending on the strength property measured, percentage increases in measured strength from 3% to 37% (TMP) and from 7% to 45% (GW) were noticed when chemical pulp dosage was increased from 25–45%.

Measured values for each property in Tables 2 and 3 were taken from figures drawn for each property as a function of NBSKP percentage and fitting a negative exponential curve to the measured data.

Significant differences in measured strength properties were seen as chemical pulp addition levels or beating was changed. In the case of TMP based sheets, tear strength and fracture toughness gave significantly higher responses to kraft dosing than did other measurements. In addition, as kraft pulp beating was increased, the handsheet strength values increased in all other studied properties except in tear and fracture toughness (see Tables 2 and 3). The effect of kraft addition on paper strength was even more pronounced in the case of the GW based sheet. Tear strength and fracture toughness increased significantly as a result of kraft addition. Other measured properties did not respond as clearly.

Testing method for runnability studies

This paper presents a method of testing base paper runnability in pilot scale. In this method paper is coated on a pilot coater in the presence of self-introduced defects and tension over the coating unit is increased until the web breaks. Tension at a break is taken as an estimate of the dynamic strength of paper.

The results of a coating trial can be used in order to

1. Evaluate the relevance of different kind of strength measurements in the case of blade coating and
2. To study the effect of changes in the furnish composition of paper or
3. To study the effects of coating parameters like tension before and after coater, changes in coating colour and in base paper.

CONCLUSIONS

Based on results obtained so far, we would like to present the following conclusions:

- Dynamic testing of base paper runnability with progressive tension method in a pilot coater is a reliable test method, however, an expensive one.
- Defects in base paper remarkably decrease the maximum tension the paper web tolerates in coating.
- The type of defect in base paper is important. Paper webs tolerate holes better than slits of the same length.
- Chemical pulp better reinforces the paper web in coating with holes,

than with slits of similar machine direction projection. This conclusion has two consequences: i) in testing paper strength, it is better to use a hole damaged specimen rather than a slit-damaged specimen; ii) in the production of base paper, in the case of increased slit frequency, the elimination of the reason is the only remedy, but in the case of damages being only holes, one can postpone the machine shut-down temporarily by increasing the share of reinforcement pulp in paper furnish.

- FEM analyses simulating stress concentrations around defects gave compatible results with those obtained in pilot coatings. FEM simulations supported our conclusions based on experimental work that reinforcement pulp is clearly less effective against cut-type defects than hole-type defects.
- The interactions of different fibres are not clearly enough understood. Our results do not fully support some other findings in this area. Instead, results presented here suggest that when it comes to fibre-to-fibre bonding, there seems to be a clear interaction between fibres of chemical and mechanical pulps. This was more pronounced in TMP-based sheets than in PGW-based sheets. This again can be partly explained because of clearly higher freeness level of PGW used in this study. Well developed mechanical pulps, combined with well beaten chemical pulps may still have unutilized potential for papermakers.
- The measurements, which are based on the work needed to propagate a cut, are not satisfactory in all respects. Fracture toughness, here only the L&W method was applied, may in some cases overestimate the benefits of chemical pulp addition and underestimate the benefits of chemical pulp beating. However, fracture toughness is clearly more suitable for predicting coating base paper runnability than the Elmendorf tear strength measurement. The results of the tear strength measurements suggest that almost no beating of chemical pulp is needed, which is clearly not in accordance with our results of runnability studies.
- Tensile strength measurement using specimen with a defect, preferably a hole, is well suited for the runnability prediction.

Results obtained so far are not definitive, but we believe that the methodology of runnability prediction described here is well suited for the purpose. The results of any method for prediction of paper runnability in aqueous coating should be compared either with results of similar pilot tests, or alternatively, with laboratory test methods including the making of selected type of defects in the specimen and preferably dampening before actual measurement. If the results then are in good agreement with each other, the method can be accepted for predicting the base paper runnability.

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Transcription of Discussion

THE IMPACT OF PAPER DEFECTS ON PAPER STRENGTH REQUIREMENTS

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Correction: On Page 1452, third but last row the sentence should be "Measurements were done with 50 mm wide samples with *20 mm* cut in the middle in cross direction to straining with L&W fracture toughness device." This error has no effect on the results or conclusions and is corrected for the sake of completeness.

Dick Kerekes University of British Columbia

Thank you for a fine paper. I think that you and the previous author showed the importance of tensile strength and stretch. Why is it that people keep on using tear as the indicator for runnability and paper strength despite all the work that has been done. Do we have any scientific explanation for this?

Kari Ebeling

Thank you, that is a good question. If one asked which camp did I believe, I probably would be more on the tear strength camp than the tensile camp. Probably during the time when you had shives in the mechanical pulp and many of the refiners produced chemical pulp where 20% of the fibres had never been developed, tear strength gave you a better life insurance than the tensile alone. In the famous paper Jasper Mardon in 1959/60 speculated with reinforcement capability of the long fibres and showed how the crack propagation was stopped if you had well refined long chemical pulp fibres. Maybe the crack propagation at that time resembled Elmendorf tear test. It is understandable that this test method has acquired many friends. Now that mechanical pulp doesn't have shives at least in well kept mills and the refiners do refine the fibres to a much larger extent so that it is more difficult to find unrefined chemical pulp fibres so we perhaps can forget about the tear strength.