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EFFECT OF FIBRE BONDING ON TENSILE STRENGTH OF PRINTING PAPERS

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ABSTRACT

Printing papers contain both chemical pulp and mechanical pulp. Chemical pulp fibres are commonly used as reinforcement, while mechanical pulp maintains opacity and printability. Modelling was performed to provide hypothetical interrelationships between strength and bonding capacity of the fibres. It is suggested that the paper strength, within certain limits, is decribed by the number and type of bonds occurring in the fibre network. The number of possible bonds was determined as the optically active total area of the fibres, *i.e.* the light scattering coefficient. Actual bonds occur only when potential bonds are accessible, and accessibility should be improved with increased fibre flexibility and compressibility. It implies that paper sheet density has to be introduced into the model along with the light scattering coefficient. In addition, the tensile strength of the paper is supposed to depend on rheological conditions, *i.e.* shearing speed that is determined as the tensile speed, and viscoelasticity of the paper describing the type of bonds.

In conclusion, the tensile strength would be described by light scattering coefficient, paper sheet density, tensile speed and viscoelasticity. By application of dimensional analysis the parameters were organised to form dimensionless quantities, which in this case resulted in the model

$$F = c\,\eta\,w/(\rho S),$$

where F is the tensile force, c a factor of proportionality, η a factor of viscoelasticity, w the tensile speed, ρ the paper sheet density and S is the light scattering coefficient of the paper sheet.

The model obtained seems to describe the strength of fibre networks formed by mixing certain McNett fractions of bleached kraft pulp and unbleached pressure groundwood in certain proportions.

INTRODUCTION

Many studies have been performed to clarify the strength of the fibre network in a paper sheet. The classical work done by Page (1) is concerned with a number of factors shown to determine the tensile strength of the paper sheet. According to the model obtained

$$1/T = 9/8Z + 12A\rho g/bPL(RBA), \qquad (1)$$

where T is the tensile strength of paper, Z the zero-span tensile strength, A the mean fibre cross-sectional area, ρ the density of the fibrous material, g the acceleration due to gravity, b shear strength per unit area of the fibre-to-fibre bonds, P the perimeter of the average fibre cross section, L the mean fibre length and RBA is the fraction of fibre surface that is bonded in the sheet.

The Page- model was later modified by d'A Clark (2), who introduced the sheet density in the model

$$1/T = K/Z + K'A\rho/bwLD, \qquad (2)$$

where b w is total cohesiveness and D is sheet density.

In search for some factor that would describe the significance of the McNett fractions of for example mechanical pulps, a bonding factor was developed (3) for a simplified case

$$c\rho S^2, \qquad (3)$$

where c is the fibre coarseness, ρ the sheet density and S is the light scattering coefficient of the paper sheet. The bonding factor seemed to describe the tensile strength although the coarseness was not introduced as it is evidently quite constant. This result encouraged to take a further step in the modelling, and some preliminary results obtained with a more complete model were presented later (4). The model will be explained here and evaluated by application of systematical results obtained with fibre networks containing bleached kraft pulp fibres and pressure groundwood.

DERIVATION OF MODEL

The tensile strength of the fibre network is supposed to depend on the number and type of bonds. The number of potential bonds correlates with the degree of fibrillation and might thus be measured as the light scattering coefficient S. However, this is not sufficient, because the fibre conformibility, *i.e.* fibre compressibility and flexibility, increase the actual number of bonds in the fibre network. Hence, also other factors must be considered in the model.

The sheet density ρ is suggested to reflect the fibre conformibility and will therefore be introduced. The rheology of the fibre network in a broad sense is finally described by the tensile speed w, that correlates initially with the shearing speed, and the factor of viscoelasticity η. If these parameters affect the tensile force F of the fibre network, the model as follows may be possible

$$F = f(S, \rho, w, \eta). \tag{4}$$

By application of dimensional analysis with the aim of forming dimensionless quantities, the following equation will be obtained

$$\rho SF/(\eta w) = \text{constant}, \tag{5}$$

where the left member is a dimensionless quantity, which equals a constant of proportionality, denoted c in the final model

$$F = c\ \eta\ w/(\rho S). \tag{6}$$

Equation (6) might be used to evaluate tensile strength values of fibre networks by plotting F *versus* the quantity $w/(\rho S)$. It is evident that the gradient of the function line estimates the quality of the fibre bonds.

EXPERIMENTAL

Softwood bleached kraft pulp and pressure groundwood were fractionated by the McNett apparatus to obtain pulp fractions retained on the 28, 48, 100 and 200 mesh screens. These pulp fractions are denoted +28, +48 *etc*, and the one that passed through the 200 mesh screen is denoted -200. The pressure groundwood was made of spruce (*Picea abies* L.) and its freeness was about 100. A certain pulp fraction was then mixed with the

+28 fraction of the softwood (pine, *Pinus silvestris* L.) bleached kraft pulp that was slightly beaten (20 SR) before fractionation. The addition of the groundwood fraction was 0, 12.5, 25, 50 and 100 % by weight, and the pulp sheet, 65 g/m^2, was prepared by recirculating the white water.

The preparation of the paper sheets including pressing, drying and conditioning (23° C, 50 % RH, 24 h) was done as normally, and they were tested by an Alwetron TCT 20 apparatus for tensile strength under different tensile speeds: 12, 36 and 108 mm/min. 12 mm/min tensile speed is standard in paper testing. Sheet density and light scattering coefficient were determined according to standard methods.

The evaluation of the model was performed by application of the diagram F *versus* w/(ρS), which model also provides information about the bonding quality.

TESTING OF THE MODEL

The sheet density ρ is a function of fibre conformibility and the light scattering coefficient S is a function of the degree of fibrillation, and hence these parameters cannot easily be tested. But the systematically varied parameter w can be tested by reducing the quantity w/(ρS) to 1/(ρS) in the evaluation diagram. The data should appear as one single function, if the developed model has relevance enough. Figure 1 indicates that the data tested evidently fall on a straight line irrespective of the varying tensile speed. - Mention is due to the fact that F here was not reduced for sheet basis weight, while it in all other cases was expressed as a "tensile index".

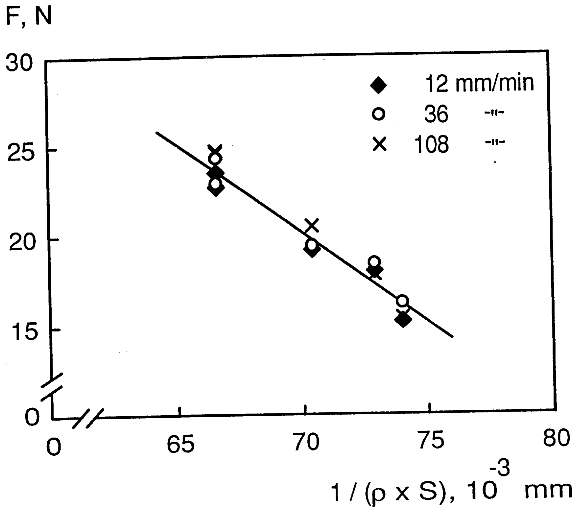

Figure 1 Tensile strength (non-indexed) of fibre network made of softwood bleached kraft pulp +28 and pressure groundwood +48 fractions *versus* 1/(ρS)

RESULTS AND DISCUSSION

Softwood bleached kraft pulp received from a mill was mixed in the form of fraction +28 (SBK +28) with the fractions +48, +100 and -200 respectively of a laboratory made unbleached pressure groundwood (PGW +48, +100 and -200) in a way described earlier. The graph representing the tensile strength of the mixture SBK +28/PGW +48 is shown in Figure 2 as a function of the quantity w/(ρS); compare with the corresponding data in Figure 1.

As visible, the data now give specific lines for the different tensile speeds tested. It is also evident that tensile testing at a higher tensile speed slightly improves the apparent tensile strength, which implies that increased speed under the conditions studied distribute the actual load on a larger number of bonds than at lower speeds. Consequently, the stress is lower and the probability for initial breakage also lower. Moreover, the gradient of the lines decreases with increased tensile speed. As a rule, the lowest F is that of SBK +28 and the highest that of "pure" PGW fractions.

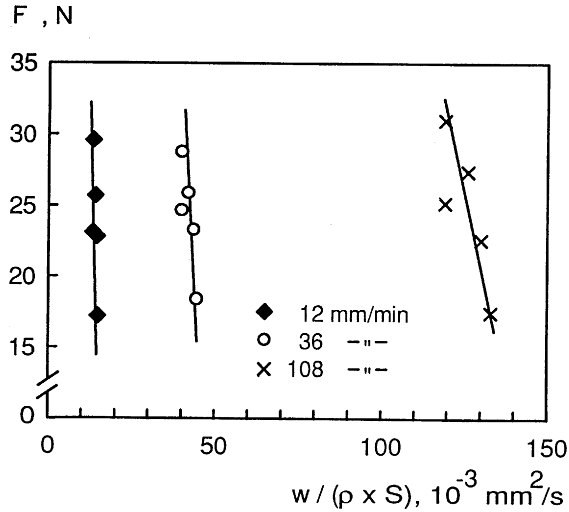

Figure 2 Tensile strength of fibre network made of softwood bleached kraft pulp +28 and pressure groundwood +48 fractions *versus* w/(ρS)

The other mixtures, *i.e.* SBK +28/PGW +100 and SBK +28/PGW -200, form lines of the same type as those shown in Figure 2, which indicates that there is a certain tensile mechanism. Instead of giving all data in the form of diagrams, the gradients of the lines are compiled in Table 1 for the tensile speeds 36 and 108 mm/min, which enables comparison of the various pulp mixtures. It is evident that coarse PGW fractions maintain the highest gradients. Irrespective of fibre furnish, increased tensile speed decreases the gradient.

Mixture	Tensile speed, mm/min		
	36	108	
SBK +28/PGW +48	-3300	-1000	Ns/mm^2
SBK +28/PGW +100	-220	-110	"
SBK +28/PGW -200	-570	-270	"

Table 1 Gradients of the F *versus* w/(ρS) plots for softwood bleached kraft pulp +28 mixed with pressure groundwood +48, +100 and -200 fractions

As to get a comparison of the finer fractions of softwood bleached kraft pulp with the fractions of pressure groundwood, the SBK +100 fraction was extracted and then added to the SBK +28 fraction under controlled conditions as described above. The graphs are shown in Figure 3, and they are lines of the same type and behaviour as previously. The gradient of the 36 mm/min line is -830 and that of the 108 mm/min line -170 Ns/mm^2. From this point of view the SBK +100 fraction seems to behave like the PGW +100 and -200 fractions at the highest tensile speed studied. At lower speed it resembles the PGW -200 fraction.

Finally graphs are presented in the diagram as to provide an evaluation of a hardwood (birch, *Betula pendula*) bleached kraft

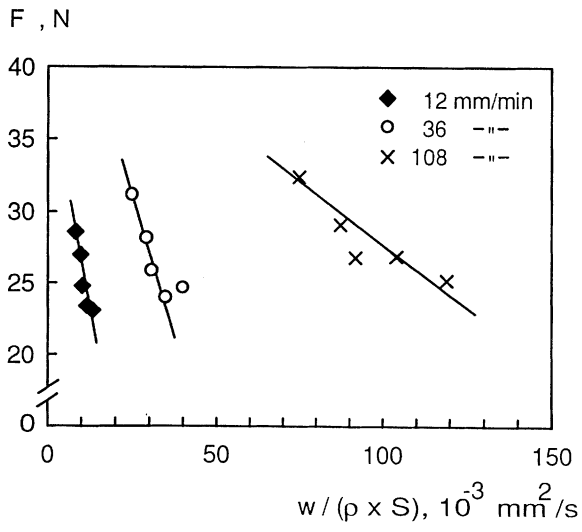

Figure 3 Tensile strength of fibre network made of softwood bleached kraft pulp +28 and +100 fractions *versus* w/(ρS)

pulp (HBK) +28 fraction in comparison with the PGW +48 fraction, when mixed with SBK +28. It is evident that PGW +48 and HBK +28 behave equivalently at low tensile speeds. At high tensile speed there seems to be some difference, although the gradient still is the same. Mention is due to the fact that HBK +28 in most cases provide some higher tensile strength than PGW +48.

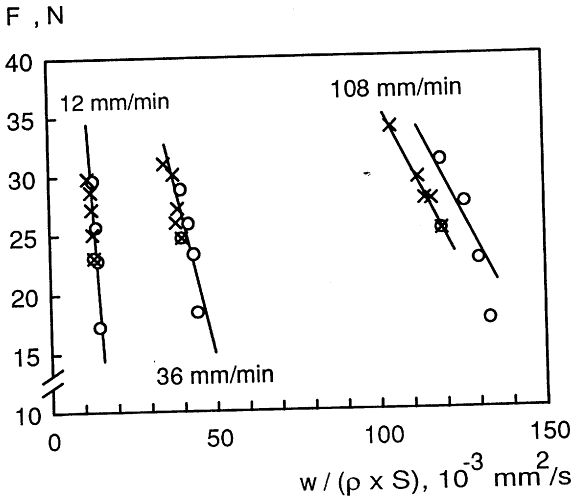

Figure 4 Tensile strength of fibre network made of softwood bleached kraft pulp +28 and pressure groundwood +48 or hardwood bleached kraft pulp +28 fractions *versus* w/(ρS); o = PGW- containing fibre network and x = HBK- containing fibre network

CONCLUSIONS

In this work the pulps studied were fractionated to provide as well defined pulp fractions as possible. In fact these pulp fractions are not homogeneous with respect to the fibre length, but nevertheless this procedure is necessary to minimise discrepancies. All the pulp mixtures studied so far behave according to the same pattern in the diagram F *versus* w/(ρS). Increased tensile speed decreased the gradient of the correlation lines, and increased slightly the tensile strength, which was explained by lower stress occurring due to the higher speed. Unloaded bonds are supposed to take part of the total load faster than loaded bonds break, which will maintain a lower stress.

The evaluation diagram produced correlation lines for fibre networks containing the same type of fibres but with varying proportions. When for example the +28 fraction of softwood bleached kraft pulp was mixed with increasing proportions of some well fibrillated pressure groundwood fraction, more bonds are introduced into the fibre network, and hence the tensile strength increases. Some well fibrillated fraction of softwood or hardwood bleached kraft pulp will cause the same effects. Comparison of hardwood bleached kraft pulp +28 fraction and pressure groundwood +48 fraction revealed that the mechanistic behaviour of these two pulp fractions was equivalent. But the hardwood fibres gave as a rule some higher tensile strength.

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Transcription of Discussion

EFFECT OF FIBRE BONDING ON TENSILE STRENGTH OF PRINTING PAPERS

B Lonnberg

B Hylander, ASSI Kraftliner, Sweden

I think one of the advantages of going to a symposium is that you can learn a lot personally. One of the things I learned yesterday was that ageing could be reversed. You could become young again if you simply expose yourself to a constantly changing environment. I thought about that this morning and I would like to address all the three speakers because one of the things I find fascinating and interesting in a function of this kind is that sometimes one contribution may shed light on some of the other contributions. In fact one of the fascinating things with Niskanen this morning was that he tended to interpret things in a stochastic way. When you talk about distributions, you normally talk about level as well as form of distribution. What both of you have talked about is introducing through fines some kind of a distribution so what I would like to hear or ask in a general sense is have you thought about your results in these more stochastic terms or distribution terms. I will give one example that I find intriguing, When we talk about strength we normally consider that it is failing because of a minimum value, When we talk about optical properties, eg light scattering as mentioned before, it is more of a level or average thing so the intriguing thing is how can we in fact influence the form of the distribution in order to maybe meet different ends.

B Lonnberg

I think this is more a question for K Niskanen perhaps. I have not thought about distributions. My philosophy as concerns strength dependence on the number of bonds between fibres and the quality of the bonds made me start thinking about what parameters could be used to describe that dependence. I do not wish to go into detail here but I finished with those very common parameters that can be measured on paper, ie sheet density, light scattering coefficient as well as the factors that are determining the rheological conditions in the sheet, that is the tensile speed and the viscoelasticity. You saw my results and the work is going on.

Dr C Fellers, STFI, Sweden

I want to ask a specific question. I got lost in your equations because I don't understand the meaning of some of the material properties in your expressions. Can you explain just what you mean by "the factor of viscoelasticity". I don't understand that word.

B Lonnberg

I am not able to explain the viscoelasticity briefly . It needs a long explanation. You could say it is describing the quality of the bonds.

C Fellers

Do you imply that the bond strength is time dependent?

B Lonnberg

Yes it is time dependent. If it would help you the dimension of the viscoelastic factor here is Ns/m^2.

C Fellers

The next question is what do you mean by "shearing speed" and "tensile speed"?

B Lonnberg

When you clamp a strip of paper and then strain it you give it a certain speed. The speed of the clamps is the tensile speed and the shearing speed, ie rate of shear, is directly proportional to the tensile speed.

C Fellers

So what is the "shearing speed"?

B Lonnberg

It is the average speed with which you stretch the bonds between the fibres until final breakage.

Dr F El Hosselny, Weyerhaeuser Paper Co, USA

You presented a model for tensile strength of paper in which fibre length is absent. We all know that fibre length is a very important component of the strength of paper. You also presented data of various mixtures of fibre fractions and you expected the graphical representation of the data to be a straight line and in many cases it wasn't. I would like to offer an explanation for this. The non linear behaviour is due to the fact that fibre length which must be different for different mixtures was not measured or considered.

B Lonnberg

These mixtures contained both long and short fibres and it is surprising that the plots anyway seem to express some mechanism. It seems that the number of bonds is the main factor here.

I Kartovaara, Enzo Gutzeit Oy, Finland

Your starting point is dimensional analysis with the aim of getting dimensionless groups. To get these you need the speed of deformation but when you show the results it turns out that you have to normalise or divide out the speed of deformation. My interpretation of this is that dimensional analysis does not apply or actually falls apart because you have to take out one of the parameters that gives you the dimensional group.

B Lonnberg

I think this is a misunderstanding. I don't have to take out the tensile speed but I did so to show that normalising will provide all the data on the same line.

I Kartovaara

I think your model says that if you multiply certain parameters you will get the tensile strength so that you should not have to use any so called normaliser to get your tensile but you have to use it so I think your model doesn't work.

B Lonnberg

I refer to my earlier comment.