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FIBRE COLLAPSE AND SHEET STRUCTURE

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ABSTRACT

A stylus profilometer has been used to evaluate the effect of wet pressing on the collapse of individual fibres from mechanical, chemimechanical and chemical pulps. The chemimechanical and chemical pulp fibres begin to collapse at low pressures and approach complete collapse at high pressures, while the mechanical pulp fibres do not exceed 80% collapse to 5000 kPa. The degree of collapse of southern pine TMP at a given pressure is about the same as that of northeastern spruce/balsam TMP. Since the thick-walled Southern pine fibres are less flexible, it is concluded that transverse collapsibility and flexibility are two independent fibre properties.

On the basis of modelling results and the difference between fibre thickness measurement from networks pressed in contact with smooth and with rough surfaces, it is suggested that wet pressure transferred locally at fibre contacts within a sheet leads to local collapse forces higher than expected from nominal wet pressure values. Fibre contacts are initially present in the unpressed sheet.On pressing, free fibre segments will be deflected into contact with other segments above or below them, producing additional fibre crossings as pressing progresses. The effective pressing pressure will be highest at the initial fibre contacts, decreasing to zero at contacts just formed at the end of pressing. Because of the demonstrated effect of wet pressure on fibre collapse, it is the thickness at the initial fibre contacts or

those formed early in the pressing process that is important in determining sheet density.

Use of the more appropriate fibre thicknesses, substantially improves the prediction of sheet density by the Interactive Multiplanar Model of sheet structure for a range of pulp types.

INTRODUCTION

Fibre collapse and the thickness of mechanical pulp fibres have been recognised as important factors in the development of pulp and ultimately sheet quality. Kibblewhite [1,2] and Kibblewhite et al. [3] investigated the effect of pulp treatment and fibre properties, including collapse, on sheet quality. Heitner and Hattula [4] and Rioux and Silvy [5] suggested that fibre collapse increased interfibre bonding thus affecting sheet density and strength. Rahman et al [6] using the method developed by Page [7], presented data showing that both breaking length and sheet density increase with increasing fibre collapsibility. Similar relationships between sheet properties and fibre collapse or thickness were reported for chemical pulps by Dinwoodie [8].

The process by which fibre thickness influences sheet structure is considered in the Interactive Multiplanar Model (IMPM) [9]. The model predicts that interlayer fibre bonding increases as fibre thickness decreases. A sheet density model based on the IMPM [10,11] suggests an even stronger dependence of sheet density on fibre thickness. However, the model relies heavily on accurate fibre thickness measurements, and does not account explicitly for relationships between fibre collapse and wet pressure.

While methods for measuring other fibre properties such as coarseness [12], and length [13,14], are well known, measurement of fibre thickness is less common. Evaluation of microscopic cross sections with the VAX Image Processing System (VIPS) algorithm [15], and confocal microscopy [16], are attractive methods but will probably remain exclusive to a few research centres. Measurement of fibre thickness by the vertical displacement of a scanning stylus, which is simple, rapid, and accessible at reasonable cost was the method used in this study.
There were three objectives of this study. The first was to quantify and compare the degree of fibre collapse of different pulps in response to wet pressure. The second was to investigate the effect of the smoothness of

the surface against which the sheet was pressed on the fibre thickness and to decide on the thickness measurement appropriate for describing sheet structure. The third was to determine if this thickness measurement would improve the correspondence between measured sheet densities and those calculated with the IMPM.

During handsheet making, fibre collapse is caused by couching and wet pressing [19]. The final magnitude of collapse is strongly influenced by chemical treatment [4,6] or by refining [2]. In this report, the effect of wet pressure on fibre collapse and the relationship between wet pressure, collapse and sheet structure is examined. It is recognized that the conditions of drying could also affect fibre collapse but this effect is not addressed here.

EXPERIMENTAL

Pulp Preparation and Sheet Making

In a previous study [11], the effect of fibre orientation on sheet density was studied using the R48 fraction of different pulps. The underestimation of sheet densities calculated using the IMPM was postulated to be due, in part to the presence in the R48 fractions of particles small enough to act as "structural fines" and fit in the interstices between fibres, and in part to inadequate measurement of fibre thickness. In this report the P14/R28 fraction was used both for fibre thickness measurements and for standard sheetmaking, to reduce the influence of such structural fines. In addition, since some difference in the mean thicknesses of the two fractions might be anticipated, fibre thicknesses of the R48 fractions were also determined with the improved method to calculate sheet densities with the IMPM for direct comparison with the previous results.

Five pulps were used in this study: two thermomechanical pulps (TMP), from north eastern softwood and from southern pine, one eastern softwood chemimechanical (CMP), one western softwood chemithermomechanical pulp (CTMP) and an eastern kraft pulp. The pulps were screened in a Bauer-McNett classifier to isolate the fibre fractions. For each pulp, four series of sheets were formed with the P14/R28 fraction, differing in the degree of wet pressure that they received. Pressures used were 350, 860, 2240 and 4830 kPa. In addition, sets of thin fibre networks, less than 0.1 g/m^2, were prepared from this fraction on glass slides and pressed at the same pressures for measurement of individual fibre thicknesses. Fibre thicknesses of the R48 fractions pressed at only one pressure, 350 kPa, were also measured.

Fibre Thickness Measurement

As described previously [11], fibre thicknesses were determined on the thin fibre networks after transfer to the glass slides, pressing, and air drying. The fibres were scanned by the stylus of a Taylor-Hobson, Model 3, surface profilometer. The mean fibre thickness for each pulp was obtained by scanning 60 fibres, each at five locations along its length.

In the previous work the fibres had been transferred to the slides under wet pressure with blotters backing the network during pressing. Fibre thickness was observed to vary greatly along the length of each fibre suggesting that prominent fibres at the blotter surface had led to an uneven transfer of pressure and thus to non-uniform collapse.

In this study, to eliminate direct contact between blotter and network fibres, networks were backed during transfer by a millipore filter which was in turn backed by two hardened smooth surface paper filters (Whatman No. 50). Figure 1 shows a diagrammatic representation of the new transfer sandwich. Figure 2 shows Scanning Electron Microscopy (SEM) photomicrographs (100X) of the surfaces used in the transfer of fibre networks. The blotter surface (Figure 2A) comprises many prominent fibres, whereas the surface of the hardened smooth surface filter and particularly of the millipore filter (Figures 2B and 2C) are much smoother.

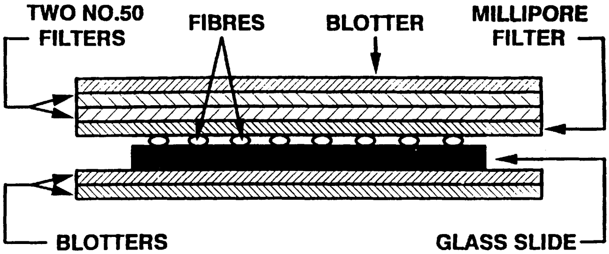

Figure 1:Improved network transfer arrangement which gave a more even pressure distribution over the network area.

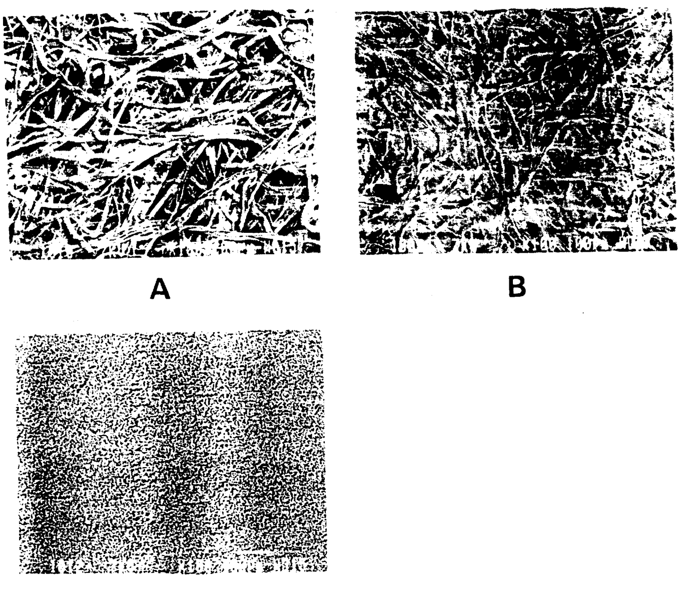

Figure 2:Surfaces used in the transfer of fibre networks(A) blotter surface with many prominent fibres. (B) hardened smooth surface filter with a fibrous but smooth appearance. (C) millipore filter with a very smooth appearance. Magnification 100X.

RESULTS

Double wall thickness was computed using the equation of Mistry [17] and Jordan [18]:

$$t_{2w}=\frac{C}{w\rho_{cell}} \tag{1}$$

where ρ_{cell} is the density of cellulose, C is the fibre coarseness and w is the fibre width. For chemical fibres, Jordan [18] found good correspondence between literature values of cell wall thickness and values obtained with the above formula. For this study, it is assumed that the density of the cell wall of mechanical and chemical pulp fibres is the same. It is recognized that equation (1) is an approximation which will overestimate wall thickness slightly because a fibre which is not completely collapsed will show a smaller fibre width than if it were completely collapsed.

In this report we define the degree of collapse as

$$\delta=[1-\frac{t-t_{2w}}{t_o-t_{2w}}]*100\% \tag{2}$$

where t_o is the uncollapsed fibre thickness, t_{2w} is the double cell wall thickness and t is the fibre thickness after a treatment that leads to fibre collapse. The initial uncollapsed fibre is assumed to be cylindrical; it follows then that the uncollapsed fibre thickness, t_0, is equal to initial fibre width, w_0. Equation (2) shows that δ = 0 when t = t_0 and δ = 100 when t = t_{2w}, which implies complete fibre collapse. The uncollapsed cylindrical fibre diameter was calculated using the following equations:

$$\text{Fibre Coarseness} = \frac{\text{Fibre Weight}}{\text{Fibre Length}} \tag{3}$$

or:

$$\text{Fibre Coarseness} = \frac{\text{FibreVolume} \cdot \rho_{Cell}}{\text{Fibre Length}} \quad (4)$$

Rearranging equation (4) yields :

$$t_0 = \frac{C}{\pi \cdot \rho_{cell} \cdot t_w} + t_w \quad (5)$$

where t_w is the cell wall thickness calculated from equation (1).

For the R48 fraction of the 5 pulp samples, mean fibre thicknesses and standard deviations obtained from profilometry measurements on networks pressed in contact with blotters and with millipore filters are listed in Table I. All values measured from networks pressed in contact with a blotter are significantly higher than those measured from the networks pressed more uniformly, with the millipore filters. An explanation why the blotter method gives higher mean thicknesses is given in Appendix 1. For the three pulps for which a comparison of standard deviations with the F-statistic is valid, more even distributions of thickness are recorded from networks pressed with the millipore filter. For relevant statistical information see Appendix 2.

Table I: Mean thickness values (R48 fractions) and standard deviation of the thickness using the blotter and the millipore method to transfer fibre networks.

Fibre Type	Mean Thickness [μm]		Standard Deviation [μm]	
	Blotter	Millipore	Blotter	Millipore
TMP-NE	18.3	12.9*	5.7	6.2
TMP-S	20.3	16.2*	7.5	6.8*
CTMP	20.4	13.4*	8.5	5.9*
CMP	15.0	9.6*	7.4	4.6*
kraft	6.9	5.0*	3.3	1.9

* Significantly different at the 95% level.

Fibre widths, and coarsenesses [12] determined on the P14/R28 samples are given in Table II together with the cell wall thickness and uncollapsed diameters calculated using equations 1 and 5.

The effects of wet pressure on fibre thickness and the degree of collapse are summarized in Table III. The table lists, for each pulp, thickness and percent collapse at the wet pressures used. At high pressures, CMP and kraft reach high levels of fibre collapse, whereas CTMP and TMP fibres only collapse to 80%. Figure 3 shows the fibre thickness of the pulps as a function of wet pressure. Figure 4 presents the same information for the degree of collapse as defined by equation (2). The degree of collapse is well represented by a simple logarithmic equation of the form:

$$\delta = A + B(\log P) \qquad (6)$$

where A and B are constants for each pulp and P is the applied wet pressing pressure. The densities of handsheets made from the P14/R28

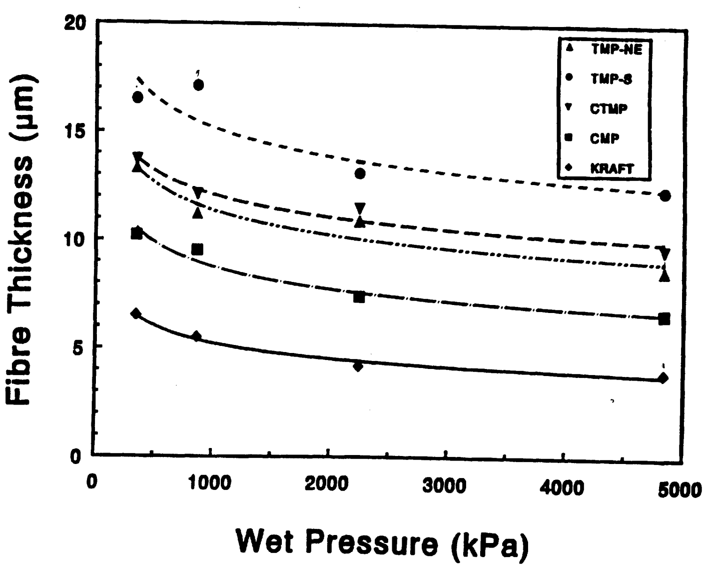

Figure 3:Increasing wet pressure decreases fibre thickness for all pulps. Fraction P14/R28.

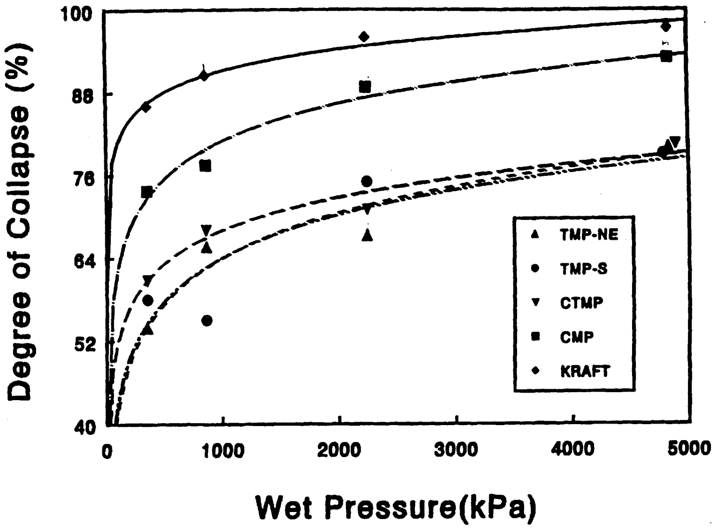

Figure 4:The degree of collapse of each fibre type in response to pressure is well represented by a logarithmic function.

pulp fractions increase markedly with pressure at lower wet pressures and approach a plateau value at pressures higher than 2,000 kPa (Figure 5). Bulk, the reciprocal of density is shown as a function of fibre thickness in Figure 6. At high pressures the relationship appears to be the same for all pulps.

Table II: Measured and calculated fibre properties (P14/R28 fraction).

Pulps	Width (microns)	Coarseness (mg/m)	Cell wall thickness (microns)	Calculated uncollapsed diameter (microns)*
TMP-NE	31.6	0.25	2.50	23.0
TMP-S	31.4	0.48	4.01	28.1
CTMP	37.0	0.32	2.75	26.4
CMP	33.0	0.27	2.65	23.9
KRAFT	38.0	0.20	1.65	26.4

* Calculated using equations (1) and (5).

Table III: Fibre thickness Measurements and percent collapse at different pressures. P14/R28 Fraction.

Pressure [kPa]	Fibre Thickness [μm] (upper) and Percent Collapse (lower) Figure				
	TMP-NE	TMP-S	CTMP	CMP	kraft
350	13.3 54	16.5 58	13.7 61	10.2 74	6.5 86
860	11.2 66	17.1 55	12.2 68	9.5 77	5.5 91
2240	10.9 67	13.1 75	11.5 71	7.4 89	4.2 96
4830	8.6 80	12.3 79	9.6 80	6.6 93	3.9 97

DISCUSSION

Comparison of the Degree of Collapse of Different Pulps

The response of different types of fibres to wet pressing is shown in Figure 4. The degree of collapse of all types of fibres increases rapidly at low pressures, then much more slowly at higher pressure. The kraft and CMP fibres, which have been extensively modified with chemicals, collapse rapidly at low pressures and approach Figure 4. The degree of collapse of each fibre type in response to pressure is well represented by a logarithmic complete collapse at 5000 kPa wet pressing pressure. The essentially mechanical pulp fibres, TMP and CTMP, which are untreated or lightly treated with chemicals, collapse less rapidly at low pressures and only reach about 80% collapse at 5000 kPa. CTMP is slightly more collapsible at low pressures but similar to the other two at high pressures. Data reported by Miller [20] also suggest a dependence of collapse on the pretreatment, in particular on beating and beating consistency of pulps.

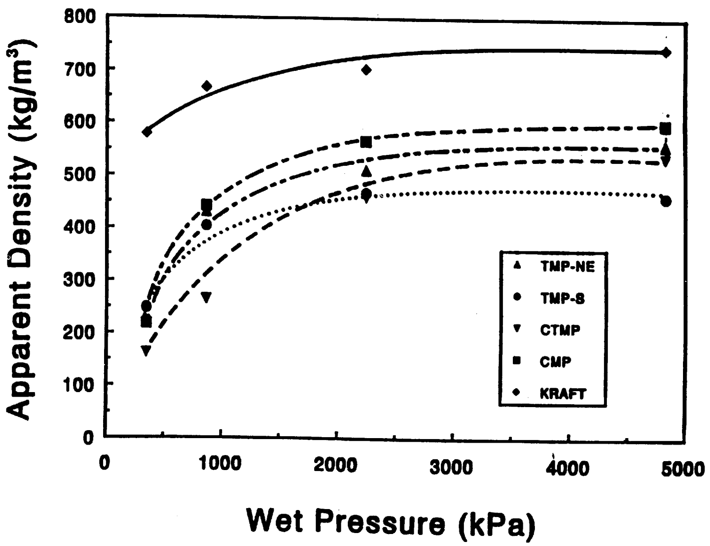

Figure 5:Sheet density increases with wet pressure for all pulps. Fraction P14/R28.

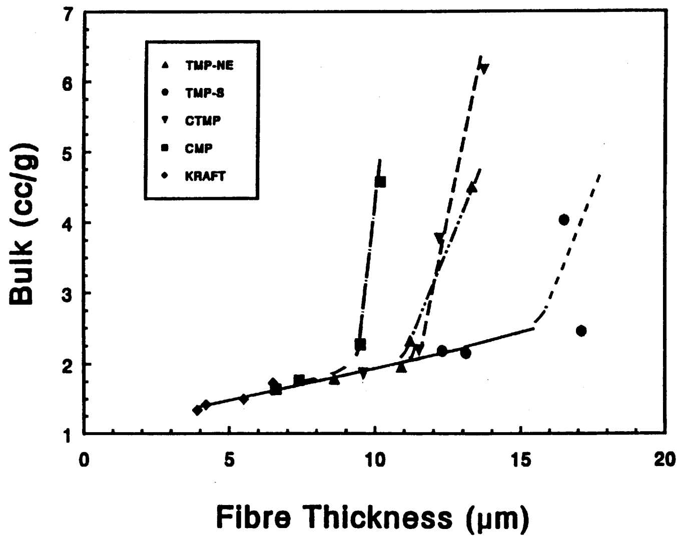

Figure 6:At high pressures bulk is a unique linear function of fibre thickness for all pulps. The solid line is a least squares fit through the two higher pressure for all pulps. Fraction P14/R28.

The similar collapse behaviour of these three mechanical pulp fibres and in particular the absence of any major difference between the northeastern softwood TMP and the TMP from southern pine, which have very different coarsenesses and flexibilities [11], indicates that fibre flexibility and transverse fibre collapsibility are distinct fibre properties which are not necessarily correlated. Since fibre collapsibility has a major effect on sheet thickness, and presumably smoothness, separation of these two fibre properties is essential to an understanding of how fibre properties control sheet structure.

One may speculate that collapsibility is determined by the S1 layer which is of similar width in the different species and has a fibril orientation at a high angle to the fibre axis, while flexibility is determined by the S2 layer which is much wider in Southern pine and has a fibril angle close to the fibre axis.

If this speculative explanation for the similar collapsibility of mechanical pulp fibres is correct it implies that mechanical pulping procedures which strip off S1 material from the fibre wall will make the fibre more collapsible, though not necessarily much more flexible.

Similarly the phenomenon of fibre roughening, which is essentially a reversal of fibre collapse, may be due to stresses "frozen" into a relatively intact S1 layer which are released on application of water. Pulps in which the S1 layer has been extensively disrupted such as groundwood, and rejects refined at high specific energy, would be expected to show less fibre roughening than TMP prepared at lower specific energy.

The results shown in Figures 3 and 5 are in accord with the inverse relationship between sheet density, and fibre thickness found by Dinwoodie [8] and predicted by the IMPM apparent density model [10]. Figure 6 however, indicates that there are apparently two different mechanisms controlling this relationship. At lower pressures bulk decreases rapidly with decreasing fibre thickness along a distinct line for each pulp. At higher wet pressing pressures, the decrease of bulk with thickness is more gradual and all pulps fall on the same straight line. Presumably, in the former region, fibre collapse and the deflection of free fibre segments described by the IMPM [11] are the predominant effects, while in the latter, all space within the sheet which can be filled by such deflections has been filled. Completion of collapse of the mechanical pulp fibres and perhaps other effects then predominate. A second effect is necessary to explain the continuing decrease in bulk at high pressure where CMP and kraft fibres are totally collapsed. A recent study of the compressibility of high consistency pulp mats has also shown that kraft and CMP approach the same density at high pressures [21].

The observation that CMP gives higher densities than TMP is in accord with the findings of Corson and Kibblewhite [22] who explained their results by better consolidation properties of the CMP. In light of our findings on the collapse characteristics of CMP and TMP, most of the density difference between sheets from the two pulps may be explained by the greater collapse of the CMP fibres.

Effect of Backing Smoothness on Fibre Thickness

This work has shown that a smooth backing during pressing will produce a lower mean, and a more uniform, fibre thickness. In addition sheet densities predicted with the IMPM using the measured fibre thicknesses, both in the previous work [11] and, as shown in the next section, in this work, are often too low. To explain these two observations we must consider fibre collapse within the sheet at the microscopic level.

When widely spaced fibres deposited on a slide are pressed with a smooth surface, pressure is applied uniformly to the whole length of the fibre and to the slide surface between fibres. The pressure received by the fibres will be comparable to the applied pressure. On the other hand, when such a thin fibre network is pressed directly with the rough blotter surface shown in Figure 2A, pressure cannot be transferred evenly along the fibre length but will be transferred at the crossings between the network fibres and the blotter fibres. The pressure at the crossings will be substantially higher than the applied pressure. This leads to non-uniform collapse along the length of the fibres and produces higher mean thicknesses (see Appendix 1).

Fibre collapse in a paper sheet, which may be considered to be a stack of single fibre networks, also occurs at fibre crossings. Fibre contacts are initially present in the unpressed sheet. On pressing, free fibre segments will be deflected into contact with other segments in layers above or below them producing additional fibre crossings as pressing progresses. The effective pressing pressure will be highest at the initial fibre contacts, decreasing to zero at contacts just formed at the end of pressing. It is therefore the thickness at the initial fibre contacts or those formed early in the pressing process that is important in determining sheet. density.

Validity of Sheet Densities Predicted with the IMPM

Figure 7 shows diagrammatically the collapse pattern within a section of a sheet. Although fibres are only collapsed at fibre crossings, the distance between free fibre surfaces in different layers of the sheet is reduced to that of the fibre thickness at fibre crossings. The assumption made by the IMPM that the thickness of a layer is equal to the average fibre thickness is not correct for fibres at pressures that give some localised collapse at fibre contacts in the sheet. The important z-directional sheet constant for input into the IMPM should be approximately the thickness at fibre-to-fibre contact.

As a result of the uniform distribution of pressure application when measuring fibre thickness after pressing with a millipore filter, thicknesses are higher than the thicknesses at locally collapsed crossings in the sheet. However, under certain conditions the thickness values obtained by the millipore transfer method may be a good approximation of the thickness values of locally collapsed fibre segments. Figure 8 compares densities calculated with the IMPM for sheets from the P14/R28, used in this work, with measured densities. At low and high pressures the

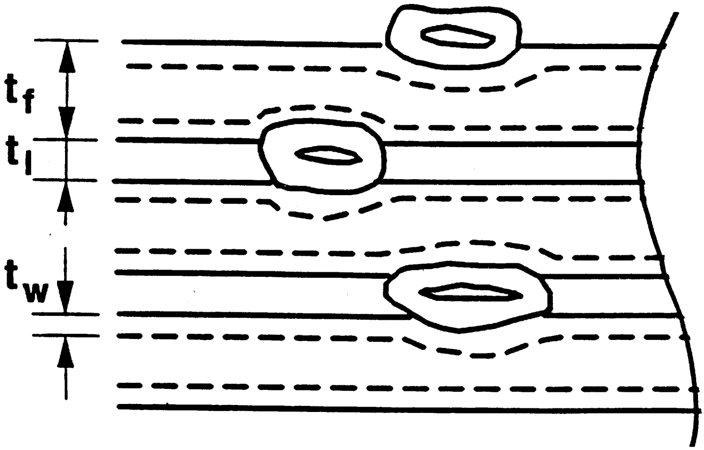

Figure 7:Schematic showing the effect of localization of wet pressure at fibre contacts on layer separation. The distance between layers, t_l, is less than the average fibre thickness, t_f. Deflection of free fibre segments to produce additional contacts has been omitted.

calculated and predicted values are in agreement. When wet pressure is so high that the fibres have approached complete collapse even under homogenous wet pressure, fibre thickness at fibre contacts is similar to the average fibre thickness measured with the millipore transfer method. At 4830 kPa pressure, CMP and kraft, which have been significantly softened by chemical treatment, are highly collapsed and for these two pulps predictions at this pressure are close to the measured values. At low pressures there is little difference between the pressure at fibre to fibre contacts because the higher pressure at contacts must arise by transfer of stress along deflecting free fibre segments and little deflection has taken place. The predicted densities for all but the kraft pulp are close to the measured densities at the lowest pressure, 350 kPa. At intermediate pressures IMPM predictions underestimate sheet density.

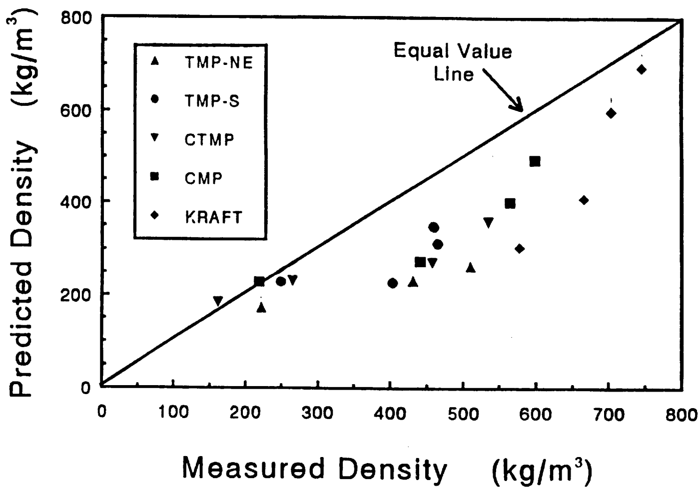

Figure 8:Comparison of measured and predicted densities forsheets made from the P14/R28 fraction and pressed to pressures ranging from about 350 to 5000 kPa.

The thicknesses of the fibres from the R48 fractions measured on networks transferred in contact with millipore filters were used to recompute apparent density values for the oriented sheets used previously [11]. As is evident in Figure 9, the IMPM density predictions with the mean fibre thicknesses obtained using a smooth backing were in better agreement with the measured sheet densities than the predictions reported previously [11], which were computed with the thickness values measured from networks transferred by the blotter method. However, the improved predictions still remain lower than measured sheet densities.

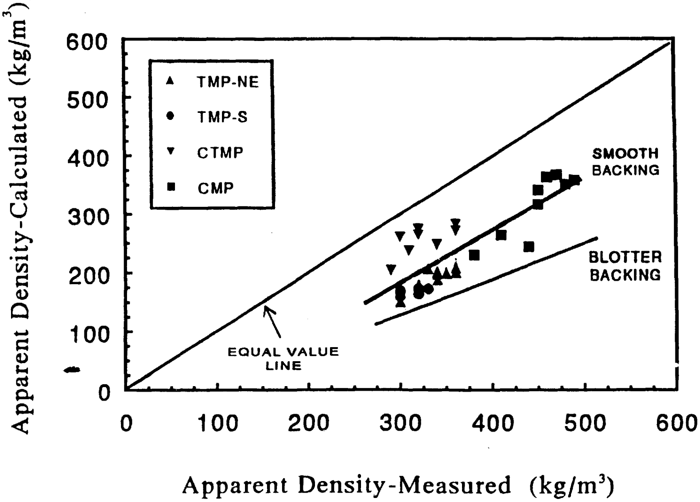

Figure 9: Correlation of measured and predicted sheet densities for sheets of reference[11] using fibre thicknesses obtained with a smooth and a blotter backing. R48 fraction.

As discussed earlier, the R48 fraction, in contrast to the P14/R28 fraction, contains "structural fines", material somewhat shorter than the mean free fibre length which will fit into the polygonal interstices between fibres in a layer, and increase the sheet density above that predicted by the IMPM. The discrepancy between measured and calculated densities for sheets from the R48 fractions is attributed to the presence of this material.

It is clear from the above discussion that the collapse behaviour of pulps and the effective fibre thickness at contact points within the sheet remain important issues both for using the IMPM, and more generally, for understanding paper manufacturing, structure and properties.

It is also apparent that it would be useful to extend the IMPM to include the effect of "structural fines" and to calculate the distribution of fibre thickness at crossings by explicitly describing the balance between fibre flexibility and fibre compactibility which controls the transfer of the pressing pressure from the pressing surface to the fibre crossings.

CONCLUSIONS

The collapse of wet pulp fibres depends on pulp type. Chemically treated fibres, CMP and kraft, are more collapsed at low pressure than mechanical pulp fibres, TMP and CTMP. At higher pressures the chemically treated fibres approach complete collapse while the mechanical pulp fibres do not exceed 80% collapse even at 5000 kPa.

There is little difference in the response to pressing pressure of thick-walled, stiff, southern pine TMP and thin-walled more flexible spruce/balsam TMP. Transverse collapsibility and flexibility are therefore independent fibre properties which must be evaluated separately.

The pressure dependence of collapse has important consequences for our understanding of the development of sheet structure during the pressing process. The pattern of fibre collapse within the sheet is focused at fibre-to-fibre contacts where wet pressure is transferred. The most important z-directional dimension of partially collapsed fibre within the pressed sheet, which is of consequence in determining sheet density, is the fibre thickness at fibre contacts.

ACKNOWLEDGEMENT

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APPENDIX 1

Network Statistics of Blotter and Fibre Crossings

The presented results of fibre thickness measurements suggest that the surface structure of the material backing a thin fibre network during wet pressing affects the degree and the uniformity of fibre collapse. A rough surface, like the blotter surface shown in Figure 2A, transfers wet pressure most directly where pronounced surface features come into contact with fibres of the thin network. In these places the pressure exceeds the pressure experienced by the fibre sections in other locations of the network so that fibres in the network are more collapsed where they are crossed by fibres at the surface of the blotter. These locations represent a small number of fibre sections in the network, while the majority of the fibre sections in the network are less collapsed.

In contrast, when the network is pressed in contact with a smooth surface, like the surface of the millipore filter shown in Figure 2C, pressure is transferred more uniformly across the entire area of the network. The pattern of collapse is expected to be more uniform resulting in a lower standard deviation of fibre thickness compared to when the network is pressed in contact with a rough surface.

In order to understand the effect of surface roughness of a backing material on the mean value of thickness, one needs to consider the frequency with which the fibres at the blotter surface cross the fibres of the network. This frequency can be estimated with network statistics. If the blotter surface layer is regarded as a two- dimensional network of weight g_l as defined by the IMPM, the number of crossings per unit length of network fibre is given by[9,10,11]

$$N_c = \frac{2g_1}{\pi C}$$

where C is the coarseness of the blotter fibres. For a softwood blotter, for which we assume C = 0.0002 g/m and a width of 36 μm, the layer weight is 0.8 g/m^2 . Thus, N_c is 2546 per meter of network fibre which yields about one crossing per 400 μm of network fibre. The average area of a crossing is

$$A_c=\frac{\pi}{2}w^2$$

The average crossing length is approximately the square root of A_c, which is 45 μm. The fraction of network fibre length affected by the high wet pressure expected at crossings with the fibres at the blotter surface is 45 μm divided by 400 μm, which gives 0.12. This means that about 88 % of the fibre length of the network fibres receive lower pressures. We believe that this results in a higher mean fibre thickness than one would expect when pressure is more uniformly applied. This explains the higher mean values obtained for fibre thickness when using the old method of slide preparation.

APPENDIX 2

Statistics of Fibre Thickness Measurements

In order to assess the difference between the mean values of fibre thickness measured with the old, blotter, and the new, millipore, method, we used the t test to compare the means of two populations. Due to the large sample sizes, the usual conditions that both population distributions be normal and that their standard deviations be equal need not be fulfilled. The H_o, the null hypothesis, was that the means were equal. H_1, the alternative hypothesis, was that the new method gave lower mean values. In all cases H_o was rejected in favour of the alternative at the 95% level.

Another inquiry was conducted into whether the standard deviation of the thicknesses obtained with the new method was lower than the standard deviation obtained with the old method. H_0 was that the standard deviations were the same, and H_1 was that the standard deviation of the thicknesses measured in the old way was higher than for thicknesses found with the new method. The hypothesis was tested with the F statistic. The F statistic assumes that the two populations are normally distributed. We used Lilliefors' test to ascertain the normality of each of the thickness distributions. In 3 out of 5 cases, both new and old fibre thickness distributions were normal (according to Lilliefors' Test) and a comparison of standard deviations was possible. In these three cases H_o was rejected in favour of the alternative that the standard deviations of thickness measured with the old method were greater than those measured with the new method of slide preparation.

Transcription of Discussion

FIBRE COLLAPSE AND SHEET STRUCTURE

R Amiri, J Gorres, et al

Dr A F Nissan, Westvaco Corporation, USA
In the last slide, the last sentence, what do you mean by fibre collapse as an intrinsic property of mechanical pulp?

R Amiri
What we wanted to emphasise is as fibre collapses from a mechanical pulp it is not really related to flexibility. It is an independent property, and we should look at it. It is something not necessarily related to flexibility of fibres. It depends on the type of pulp too.

A Nissan
Would not that apply to other pulps?

R Amiri
Well for a chemical pulp in general they are very highly collapsed. For example for a kraft pulp, even at 350 kPa the starting pressure we had almost 88 or 90% collapse. So you cannot really use that for chemical pulp it is basically for mechanical pulp which becomes important. We have a wide range of collapse of fibres so it is not really applied to chemical pulps and that is what I wanted to distinguish between chemical and mechanical.

J F Waterhouse, Institute of Paper Science & Technology, USA
Have you looked at the relationship between Relative Bonded Area (RBA) and apparent density and could you also comment on other things that might be motivating this study?

R Amiri
This is part of our work which will be published shortly.

J F Waterhouse
Would you be able to generally sketch what the relationship would be between RBA and density for the pulps you have discussed in the modelling work?

R Amiri
Unfortunately I cannot talk about these results but they will be published very soon. What I can say is that we did not look at RBA for the moment in the density model but at shear bond strength.

Prof D Wahren, Stora Teknik AB, Sweden
What was the method employed to measure sheet thickness?

R Amiri
The standard TAPPI method not soft platen. We use that because we feel that this is more in line with the IPM because I feel that what we say is the superposition of layers. So each layer is important so we use that so the surface roughness should take that into consideration.

D Wahren

That would imply that for the measured density, had you used a more modern method, it would be even higher than indicated in your diagrams.

R. Amiri

The caliper would be reduced.

D Wahren

These sheets were airdried. Were they prevented from wrinkling to give what MacGregor calls micro-striations?

R Amiri

This is the standard handsheet so we used the same method of handsheeting dried under restraint.