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SURFACE PROPERTIES OF HARDWOOD PAPERS IN RELATION TO FIBRES AND VESSELS

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Synopsis The surface properties of hardwood papers are determined largely by the nature of the fibres and vessel elements (henceforth referred to as *vessels*) and the possibilities for interfibre and fibre to vessel hydrogen bonding. Experiments with *Eucalyptus* species and tropical hardwoods covering a wide range of wood densities have shown that surface smoothness as well as bulk mechanical properties depend on the lateral conformability of the fibres and that the response to beating, in terms of surface smoothness, is more marked for pulps with fibres of high Runkel ratio. Effective removal of vessels from pulps was accomplished on a laboratory scale by a method based on that used by Jacquelin for flocculation studies. Vessel removal resulted in a drastic reduction in the vessel IGT pick number. A comparison between the picking tendency of two eucalypt pulps with similar external fibre and vessel dimensions, similar vessel concentrations, but with greatly different fibre lumen diameters, indicated that the bonding strength between fibres and vessels is an important factor in picking, as well as vessel size and concentration. Laterally conformable fibres from low density woods can provide the necessary fibre-to-vessel bonding. Beating has a very pronounced effect in reducing pick number and the question arises whether breaking up of the vessels or improved bonding is mainly responsible. The wider use of hardwood resources for fine papers, particularly for offset printing papers, depends on the surface properties that can be attained.

Introduction

THE concepts developed here are of general application to hardwoods, although we have been concerned in these experiments with eucalypts and tropical species. Both of these resources are providing a rapidly increasing proportion of the world's pulpwood; the extent to which they can be used for high grade writing and printing papers is of major economic significance and depends largely on the surface properties attainable. The elements of the wood

Under the chairmanship of Prof. V. T. Stannett that are the main determinants of the surface architecture of the paper sheet are the fibres and vessels; we shall deal with their effects on surface roughness, as assessed by profile recording and airleak methods, on the degree of picking in offset printing and on the appearance of the surface as determined by scanning electron microscopy.

Experimental procedures

Pulp preparation—For some experiments, a range of eucalypt species were selected, covering the basic density range 300–900 kg/m^3 and a sufficient number of kraft pulps were prepared from each wood to enable the effect of wood density on various properties to be assessed either on the basis of constant kappa number or constant yield.[1, 2] Only total alkali was varied, from 10 to 33 per cent as Na_2O as percentage of oven-dry weight of unextracted wood. The other conditions were as follows—2 litre reaction vessels, heated in an air bath; sulphidity 25 per cent; liquor-to-wood ratio 3·5:1; cooking schedule 1·5 h to 170° C, 2 h at 170° C.

For the work on vessel separation, bleached kraft pulps were prepared from two eucalypts, *E. regnans* and *E. tetrodonta.*

The tropical hardwood pulps were prepared as part of a major assessment of the rain forests of Papua New Guinea as a source of pulpwood.[3] Pulping conditions for the sheets used in the work on surface smoothness were—total alkali 15 per cent as Na_2O on oven-dry wood; sulphidity 25 per cent; liquor-to-wood ratio 5:1; cooking schedule 1 h to 170° C, 2 h at 170° C. For the work on the effect of vessels on picking, the total alkali was varied from 15 to 20 per cent so as to produce a pulp with a kappa number in the range 18–21.

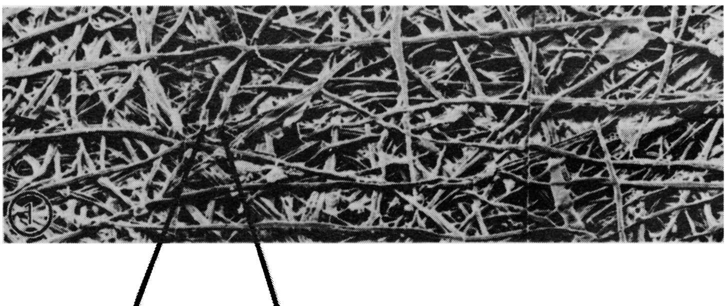
Handsheet preparation—Pulps were beaten in the PFI mill under the following conditions—charge 24 g, concentration 10 per cent, load 1·8 kg/cm, relative speed 6·0 m/s. Handsheets were made at 60 g/m^2 according to APPITA standard method P 203 m-62.

Surface profiles—An instrument has been developed[2] to measure surface roughness. A sapphire stylus attached to a linear displacement transducer records the profile of a paper sample moving beneath it. Compared with profilers designed for metal surfaces, it operates at a very low speed and pressure and is therefore well suited for studies of easily deformed paper surfaces. Yet scanning electron micrographs of paper from high density wood still revealed some residual deformation of the surface along the path of the stylus (Fig. 1). Such deformation was far less marked with paper from wood of low density such as *Eucalyptus regnans.*

The transducer output is fed into a pen recorder, also digitised and recorded on punched paper tape for computer analysis. The length of traverse for each sample is 5 cm, which is divided into 50 equal intervals within each of which the RMS of the vertical displacement is calculated. Within each scanning interval, 120 readings are taken at equal distances along the sheet, so that 6 000 readings are processed for each sample.

For each scanning interval, the RMS is calculated as $[(\bar{y}_i - y)^2]^{\frac{1}{2}}$, where $\bar{y}_i$ and y refer to individual and mean displacements[2] and a 'wavelength' WL is also calculated as $2.\text{RMS}\ d.\pi\ [(\Delta y)^2]^{-\frac{1}{2}}$, where d is the distance between readings and Δy is the difference between successive readings.[2] For each sample, the means $\overline{\text{RMS}}$ and $\overline{\text{WL}}$ are calculated from the 50 RMS and WL values for each scanning interval.

Surface smoothness—An airleak method was also used in some tests. The instrument was the Parker Print-Surf, which was operated at a clamping pressure of 10 kgf/cm^2, corresponding to offset printing conditions.



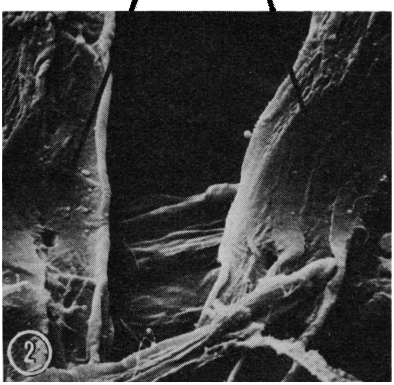


Fig. 1—Scanning electron micrographs—(*1*) Montage of three micrographs to show path (arrowed) of stylus across *Eucalyptus tetrodonta* paper surface (×100); (*2*) Enlargement of fibres at points indicated by heavy lines to show stylus imprint upon them (×2 000)
(courtesy of Dr G. Scurfield)

A comparison was made between the smoothness (or roughness) measurements made by both the surface profile and airleak methods for a group of 30 kraft papers prepared from different hardwood species, the readings lying in the range 2·5–7·5μm. The correlation coefficient was 0·93 and the residual standard deviation 0·53. The linear relationship of best fit was

$$P = 1{\cdot}47\ S - 0{\cdot}72,$$

where P is the Print-Surf reading and S the $\overline{\text{RMS}}$ value as calculated above.

Vessel separation—A technique was used similar to that of Jacquelin.[4] Beakers of 3 litre capacity were set at 45° to the horizontal and rotated with an electric motor and pulley arrangement at a constant speed of 64 rev/min, corresponding to a beaker peripheral speed of 0·5 m/s. The pulps were fractionated at a concentration of 2·7 g/l and each beaker contained 600 ml of stock. As in Jacquelin's experiments, coherent flocs were formed and the process appeared to be completed after 10 h treatment. The flocs were separated from the suspension on a Somerville fractionator with a 60 mesh screen (size of opening 0·25 mm). A gently flowing supply of distilled water was used to prevent disruption of the balls. After removal of all the suspension, the flocs were washed off the screen into a beaker and thickened. They were then treated for 100 counter revolutions in a British standard disintegrator to produce a uniform pulp suspension.

After the first fractionation, it was found that the coherent flocs still contained an appreciable concentration of vessels, so the initial floc fraction was fractionated again under the same conditions as in the previous treatment.

Determination of vessel-to-fibre ratios—Each sample was prepared by filtering a very dilute suspension of suitably dyed pulp or pulp fraction on to a sintered stainless steel Buchner funnel and removing the fibres with clear adhesive tape, which was then stuck on to a glass microscope slide. The number of fibres and vessels in a given area were determined with the aid of a projection microscope. The weight ratios were crudely estimated from the number ratios from measurements of the lateral dimensions of the vessel elements and taking the cell wall thickness of fibres and vessels as the same in any particular sample.

Determination of pick number—For the experiments of *E. regnans* and *E. tetrodonta*, the pulp fractions were beaten in the PFI mill for 1 000 rev. Two strips each 20 mm wide were cut from each handsheet for the IGT printability tester. For the tests on *E. regnans* and *E. tetrodonta* pulps, coherent flocs and suspensions, the linear printing speed was 0·27 m/s, the printing load 50 kg, the test atmosphere 65 per cent rh, 20° C and the printing ink was specially prepared to give a constant high tack. The test papers were backed with a rubber blanket and printed with an inked aluminium disc. For the tests on the tropical woods, the printing speed was 0·60 m/s, the load the same as above, the test atmosphere 50 per cent rh, 20° C and the ink was similar to that previously used, but of lower tack. Strips were printed in random order. Immediately after printing, the wet print surface was brushed in order to lift up the vessels that had been dislodged during printing. If this is not done, some of the vessels may resume their original position on the paper surface and would not be counted in the subsequent analysis. Picking tendency was assessed by marking off a set area on the printed surface and counting all the white spots greater than about 120 μm in width. To aid in the measurement of pick number, the vessel spots were ringed first, then counted. The test results given are expressed on the basis of an arbitrary area 240 cm^2.

Wood density, fibre morphology and surface smoothness

THE lateral conformability of a fibre can be defined[2] as the reciprocal of the load required for collapse, which can be evaluated from the load/deformation curve.[5] On the one hand, lateral conformability depends on the ratio of lumen to fibre diameter[6] and this in turn is closely related to wood density.[2] On the other hand, the lateral conformability of the fibres largely determines the relative bonded area of a paper sheet, hence those mechanical and optical properties dependent on interfibre bonding. Of course, this is a simplification and many other factors intervene in these relationships.

Wood density influences the surface smoothness of paper as well as the bulk properties, fibres that collapse easily into ribbons giving smaller protrusions than do uncollapsed fibres at fibre crossings at or near the surface of the sheet. This can be appreciated from scanning electron micrographs (Fig. 2, upper pictures) in which paper from a low density species, *Eucalyptus deglupta*, is compared with that from a high density species, *E. nesophila*.

A study[2] of the surface profiles (roughness, $\overline{\text{RMS}}$ and wavelength $\overline{WL}$) of papers made from eucalypt woods ranging in basic density 300–900 kg/m^3 has given the following results—

1. When assessed at constant kappa number, surface roughness rises over the wood density range 300–600 kg/m^3, in accordance with the reduced possibilities for collapse, then declines somewhat as a consequence of lower pulp yield, the loss of substance in each fibre leading to increased conformability.
2. When assessed at constant pulp yield, surface roughness rises continuously with wood density.
3. Surface roughness declines steeply with increased cooking in the higher range of kappa number, less steeply as delignification proceeds. The presence of shives in the less well cooked pulps contributes to high values of both $\overline{\text{RMS}}$ and $\overline{\text{WL}}$.
4. Bleaching has no marked effect on surface properties.

5. Beating has little effect on the surface roughness of papers from woods of low density, the fibres of which already have sufficient lateral conformability to provide a smooth surface, but the thicker-walled fibres from high density woods undergo changes leading to a decrease in surface roughness.

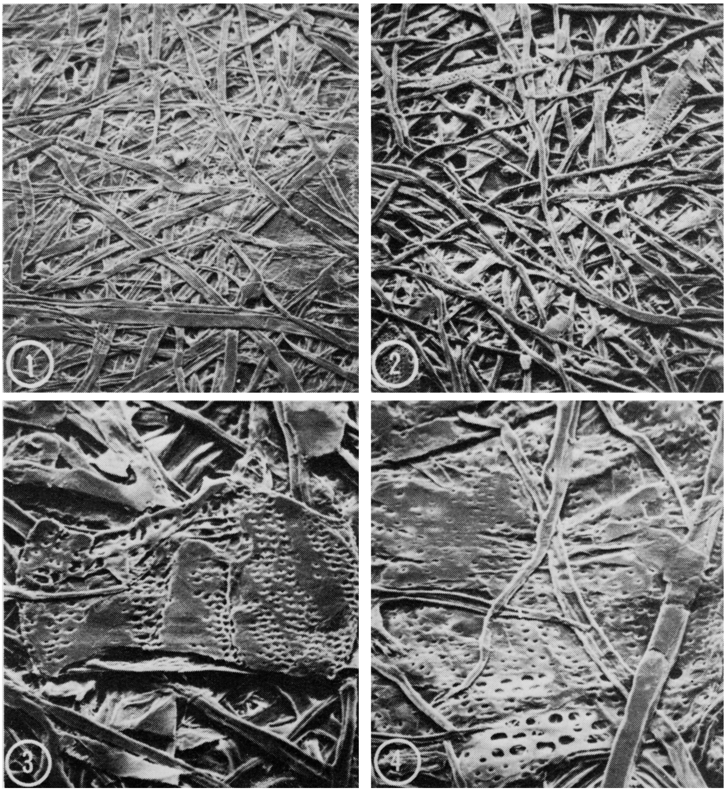


Fig. 2—Scanning electron micrographs— (*1*) Surface of *Eucalyptus deglupta* paper; (*2*) Surface of *E. nesophila* paper (*3*); Vessel element lying on the surface of *E. calophylla* paper; (*4*) Vessel element bound into the surface of *E. diversicolor* paper by fibres
(*1*) and (*2*) ×100; (*3*) and (*4*) ×200
(courtesy of Dr G. Scurfield)

The effect of beating on the surface properties of the paper can be seen from scanning electron micrographs, which confirm the results obtained from the roughness measurements. These aspects are to be discussed elsewhere.[7]

Somewhat similar results have been obtained with a series of 30 tropical

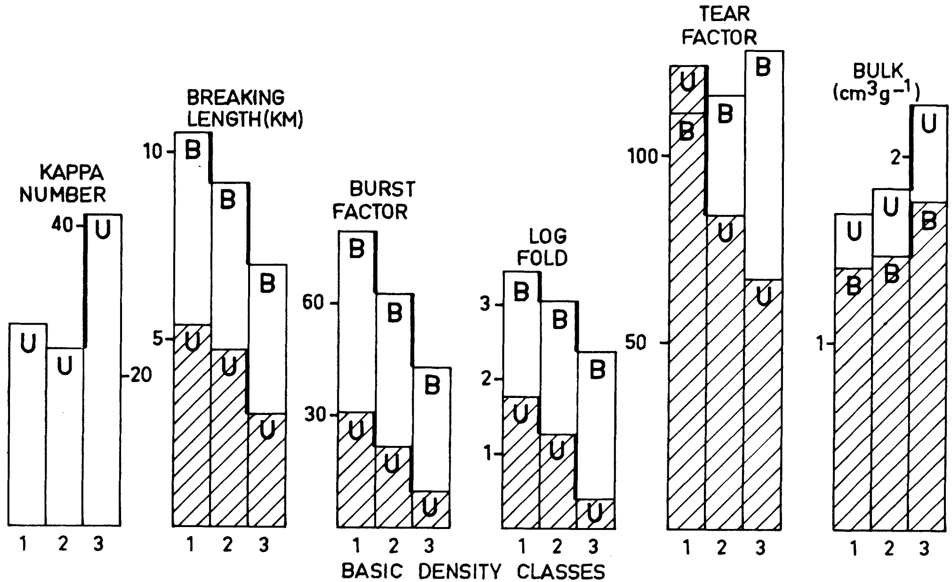


Fig. 3—Effect of basic density of wood on pulp and paper properties for a group of tropical hardwoods, as described in reference; [3] class 1 is 250–400 kg/m^3; class 2 is 400–550 kg/m^3; class 3 is 550–700 kg/m^3; heavy vertical lines denote highly significant differences; other differences within beaten (B) or unbeaten (U) groups not statistically significant; beating is 4 000 rev PFI

rainforest species from Papua New Guinea. The wide diversity in structural features resulted in a much wider scatter than for the eucalypt species when the surface roughness of the paper was plotted against wood basic density. A similar situation was found for the trend in bulk properties,[3] but, when the species were divided into three groups according to their basic density (250–400, 400–550 and 550–700 kg/m^3), highly significant effects were revealed. Basic density clearly has a strong influence on the bonding properties of the paper (burst, breaking length, folding endurance), particularly in the higher part of the density range, when the higher Runkel ratio of the fibres reduces lateral conformity (Fig. 3). The surface smoothness results are analysed in Table 1. The high density woods yield papers with rougher surfaces, but the pulp fibres can be modified by beating so as to improve the smoothness of the sheet. The low density woods again yield pulps that, in terms of the surface smoothness of the paper sheet, do not respond to beating.

TABLE 1—EFFECT OF WOOD DENSITY AND BEATING ON SURFACE SMOOTHNESS OF KRAFT PAPERS FROM 30 INDIVIDUAL TROPICAL HARDWOODS

Smoothness measured with Parker Print-Surf

Beating, PFI rev	Surface smoothness (μm) for each density range (kg/m^3) 250–400 (Group 1)	400–550 (Group 2)	550–700 (Group 3)
0	4·8	4·9	7·1
4 000	4·8	4·4	5·6

SIGNIFICANCE OF DIFFERENCES BETWEEN DENSITY GROUPS

1 versus 2 Unbeaten	1 versus 2 Beaten	1 versus 3 Unbeaten	1 versus 3 Beaten	2 versus 3 Unbeaten	2 versus 3 Beaten
Not significant	Not significant	$P<0{\cdot}01$	$P<0{\cdot}01$	$P<0{\cdot}05$	$P<0{\cdot}05$

Vessels and printability

ONE of the disadvantages of hardwood pulps is the tendency of vessel elements to pick out of the paper surface during printing, particularly in offset lithography. Colley[8] has studied the picking tendency of paper made from bleached kraft pulps of two *Eucalyptus* species, *E. regnans* and *E. tetrodonta*, which differ mainly in the thickness of their cell walls. The wood and pulp used for this work had the following morphological characteristics—

Wood properties	*E. regnans*	*E. tetrodonta*
Fibre diameter, µm	14·3±2·5	14·7±2·2
Lumen diameter, µm	9·6±2·2	3·8±1·6
Vessel frequency, mm^{-2}	9±5	11±3
Pulp properties		
Fibre length, µm	860±20	910±20
Vessel length, µm	380 (155–526)	404 (309–619)
Vessel width, µm	157 (77–289)	166 (113–237)

The great difference in size between vessels and fibres contributes to the problems associated with printing papers containing hardwood pulps. The removal of vessels from the stock would thus be expected to lead to significant improvements in printing behaviour. In order to study this problem, various separation techniques were considered. Normal screening is not very successful, owing to the tendency of the fibres to form networks that may entrap the vessels. The technique of Marton & Agarwal[9] can give good results, but requires much expertise and necessitates cooking of the pulp to an advanced stage. As mentioned earlier, the equipment eventually used was similar to that developed by Jacquelin[4] in his studies of fibre separation and the flocculation behaviour of pulps. The effectiveness of the fractionation technique was determined by counting the ratio of vessels to fibres in samples of the pulp fractions deposited on microscope slides. Photomicrographs of the final pulp fractions are shown in Fig. 4 and it can be seen clearly that the vessels have been very effectively removed. More quantitatively, fibre-to-vessel ratios found by Colley[8] in the fractions are shown in Table 2, together with the results of measurements of vessel pick number carried out on IGT print test strips. It can be seen that removal of vessels drastically reduces the pick number, whereas the papers made from the vessel-enriched suspension show a higher pick number than the original pulp.

TABLE 2—EFFECT OF REMOVING VESSELS FROM BLEACHED KRAFT EUCALYPT PULPS ON VESSEL IGT PICK NUMBER

Beaten 1 000 rev PFI after fractionation

Species	*Pulp fraction*	*Vessel-to-fibre ratio*		*Vessel pick number**	
		By number	*By weight*	*Mean*	*Coefficient of variation, per cent*
E. regnans	Original	1:327	1:89	350	26
	Coherent flocs	1:10 230	1:2 770	30	57
	Suspension	1:310	1:84	503	23
E. tetrodonta	Original	1:281	1:55	1 495	17
	Coherent flocs	1:2 578	1:505	51	57
	Suspension	1:66	1:13	2 502	14

* Per 240 cm^2 (10 strips each 2 cm × 12 cm)

The greater picking tendency shown by the *E. tetrodonta* pulps as against *E. regnans* seems to exceed that attributable merely to differences in the number of vessels, as can be seen by plotting vessel-to-fibre ratio against vessel pick number (Fig. 5). The fibres of the two species differ greatly in lumen diameter and cell wall thickness, hence in lateral conformability; apparently, the greater interfibre bonding strength of the *E. regnans* paper also assists in bonding vessels more firmly to the surface of the sheet. The appearance of a vessel in the surface is illustrated in Fig. 2 (lower pictures). In some situations, the vessel lies flat on top of the fibre assemblage; in others, it is held to the surface under restraining fibres.

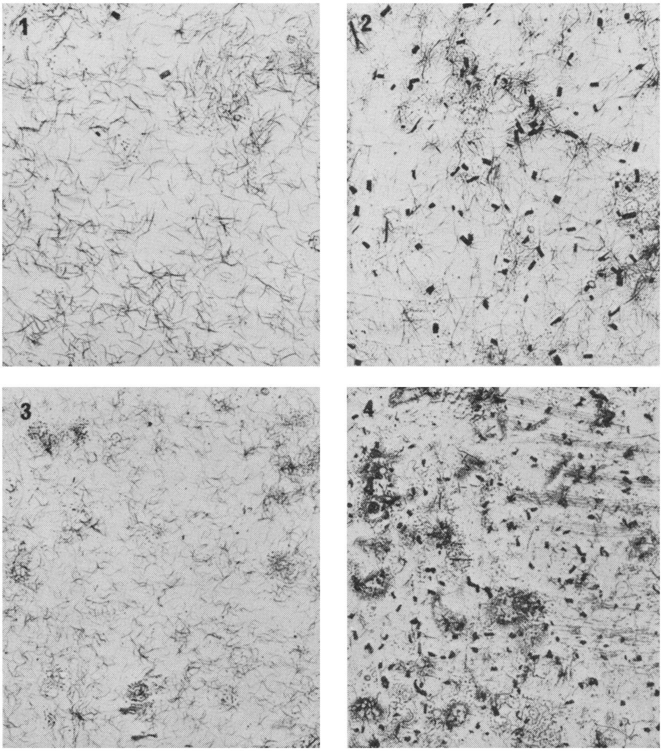


Fig. 4—Photomicrographs of bleached *Eucalyptus* kraft pulps—
(*1*) *E. tetrodonta* coherent flocs; (*2*) *E. tetrodonta* suspension;
(*3*) *E. regnans* coherent flocs; (*4*) *E. regnans* suspension
Note absence of vessels in (*1*) and (*3*)

Beating has a very pronounced effect on the vessel pick number, as shown in Table 3 for a number of pulps from eucalypts and tropical hardwoods. The question arises whether the improvement on beating arises principally from

TABLE 3—EFFECT OF BEATING ON VESSEL IGT PICK NUMBER

Unbleached kraft pulps, kappa number near 20

	Vessel pick number for each beating point (PFI rev.)*					
	2 000		*4 000*		*8 000*	
Pulpwood	*Mean*	*S.D†.*	*Mean*	*S.D.†*	*Mean*	*S.D.†*
Dillenia schlecteri	382	78	80	50	14	8
Eucalypts, ash plus mixed, Vic.	120	41	43	23	12	6
Eycalypts, mixed, Southern N.S.W.	598	116	64	22	23	18
Eucalyptus regnans	124	31	38	22	38	23
Ficus microcarpa	943	119	409	102	74	24
Intsia palembanica (kwila)	683	100	325	58	94	42
Myristica globosa	222	52	66	22	31	14
Pimeleodendron amboinicum	307	86	41	20	16	8
Pometia pinnata (taun)	547	56	196	60	76	41
Terminalia solomonensis	1 283	115	629	82	228	74
Area V composite C	809	16	374	82	79	24
Area V composite D	890	116	346	71	74	41

* Expressed per 240 cm^2 † Standard deviation

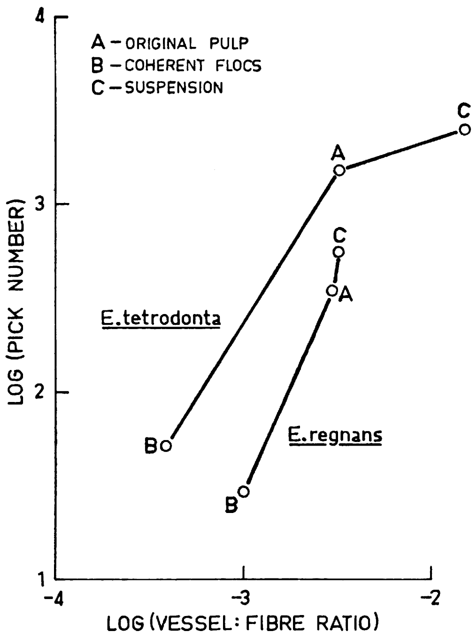


Fig. 5—Relationship between vessel-to-fibre ratio (by number) and vessel IGT pick number for *E. regnans* and *E. tetrodonta* bleached kraft pulps and fractions

breaking up of the vessel segments or from improved hydrogen bonding between fibres and vessels. Experiments to resolve this point are now in progress. The differences in vessel pick number between different species cannot be correlated with the number of vessels in a given area of the sheet, as shown by the data of Table 4. Differences in vessel size presumably play a considerable part in determining the degree of picking and, as indicated earlier, the efficacy of fibre-to-vessel bonding is also an important factor, which in turn is determined largely by fibre structure and processing.

TABLE 4—VESSEL PICK NUMBER IN RELATION TO VESSEL DIMENSIONS AND VESSEL CONCENTRATION

Species	*Vessel-to-fibre ratio*		*Vessel area,* mm²*	*Vessel concentration,* g⁻¹*	*Vessel pick number†*
	By number	*By weight*			
Dillenia schlecteri	1:21	1:4·5	0·810	6 100	382
Eucalyptus regnans	1:327	1:89	0·060	28 450	124
Ficus microcarpa	1:270	1:105	0·089	12 500	943
Intsia palembanica	1:187	1:69	0·188	10 550	683
Myristica globosa	1:200	1:40	0·240	12 400	222
Pimeleodendron amboinicum	1:173	1:39	0·201	9 400	307
Pometia pinnata	1:267	1:85	0·125	6 350	547
Terminalia solomonensis	1:252	1:92	0·098	11 150	1 283

* In unbeaten pulp † Expressed per 240 cm^2; pulp beaten 2 000 rev PFI

Finally, reference should be made to extensive experiments at U.S. Forest Products Laboratory,[10, 11] which have defined optimum refining and surface sizing conditions for reducing picking in printing papers containing oak pulps.

Acknowledgements

The following colleagues have assisted in various ways—Mr V. Balodis, Miss N. Ditchburne, Mr A. Logan, Mr R. McNamee, Dr G. Scurfield, Mr J. Ward.

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Discussion

Dr J. Marton I would like to comment on the Z-directional distribution of vessel segments in paper made on Fourdrinier papermachines. Unlike the handsheets of Dr Higgins, the machine-made papers usually are two-sided. It is a well-known problem that the top side of the sheet is more involved in vessel segment picking troubles than the wire side. Vessel segment picking is especially disturbing when making hardwood-based offset paper.

A still widely held belief has been that the vessel elements float on to the *top side* while the sheet is being formed on the wire, just as there is an accumulation of ash in this direction. Byrd & Fahey (*Forest Prod.J.*, 1969) found, however, more vessel elements surprisingly in the *wire side* of the sheet. If I remember correctly, they investigated unfilled hardwood furnishes. Thus, the question remains why the top side releases more vessel segments if their number is, in fact, larger on the opposite side of the sheet.

Most printing papers contain fillers to achieve desired optical properties. We investigated paper rawstock made on Fourdrinier machines with speeds ranging 700–1 500 ft/min; the grammage of the rawstock ranged 35–55 lb/ream. The fibre furnish contained hardwood (2/3) and pine (1/3) bleached fibres. Since the desired level of ash in the sheet was around 10 per cent, the headbox furnish could have contained about 25 per cent pigment and, in addition, about 30 per cent cellulose fines. Thus, an actual furnish contains less than 50 per cent of fibre.

1 mg furnish contains

7 500	hardwood fibres
750	pine fibres
60	vessel fragments
15–20	oak vessel elements
0·23 mg	pigments
0·27 mg	cell fines

Sheets from five different machines were split into two parts on a Beloit splitter, ash was determined in the splits, fibre content and vessel segments were counted on a slide by the usual microscope technique. The felt side splits usually contained 2–3 times as much ash as the wire side parts. The

Under the chairmanship of Prof. V. T. Stannett amount of vessel segments proved to be, however, identical in both top and wire side parts (see Table 1).

In general, 1 mg of the actual headbox furnish (about 0·5 mg fibres) contained around 8 000 hardwood and 800 pine fibres, a good number of disintegrated vessel fragments and around 60 largely untouched potentially harmful, mostly oak vessel segments. Even though the great majority of the vessel elements had been disintegrated during refining, there would be hundreds of thousands of potentially harmful vessel segments on the paper surface contacting the tacky printing forme on a press. Even a few picks are judged as unacceptable, thus the vessel elements must be bonded in the sheet with better than 99 per cent efficiency in order to pass the mill quality control test.

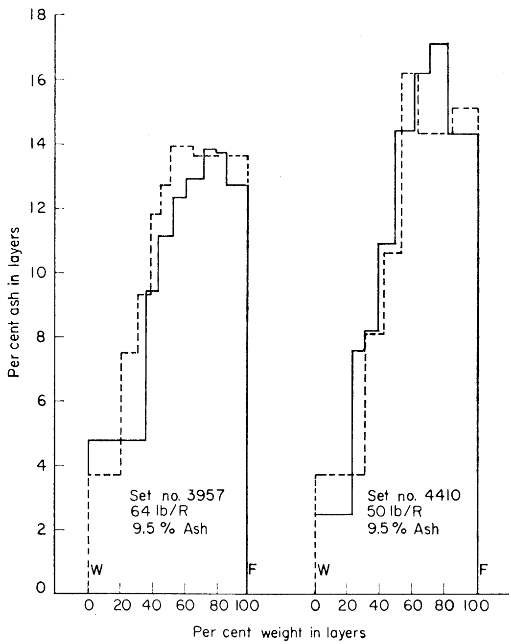

Fig. I

I suggest the following explanation for the lower surface strength and inferior vessel segment pick resistance of the top (felt) side. It has been demonstrated by several authors that ash distribution exhibits a very skewed form (towards the felt side) in machine-made (Fourdrinier) papers. A typical ash distribution curve is presented in Fig. I. A rawstock that has an average 10 per cent ash content may have only 5 per cent ash in the wire side surface layer, but over 15 per cent ash in the felt side layer, directly in contact with the printing plates. The fillers are adsorbed on fibre surfaces, physically preventing fibre-to-fibre contact. The more filler, the more extensive this debonding effect. The reduced interfibre bonding also means weakened bonding between fibre and vessel element. We propose that the increased vessel segment picking potential of the top (felt) side of the sheet is not caused by any increase in the number of vessel segments present in the felt side layer (compared with the wire side), but the surface pick resistance weakens because of the increased ash content on the felt side effecting debonding between fibre and vessel segments in the top side layer. The practical solutions sought must then counteract this effect.

TABLE 1—VESSEL SEGMENTS AND ASH IN THE SPLITS
(Beloit sheet splitter)

Paper-machine No.	Grammage, l/r	Weight ratio W/F at split*	Total number of vessel elements and fragments per mg oven-dry pulp (S+K) W	F	Oak elements and fragments per mg oven-dry pulp (K) W	F	Distribution ratio (S+K) W/F	Total ash, per cent	Ash ratio W/F
3	45	1·2:1	51	37	15	12	1·4:1	5·9	0·6:1
5	58	1·1:1	53	52	12	14	1:1	8·3	0·6:1
8	39	0·6:1	60	62	20	18	1:1	9·6	0·3:1
9	32	0·9:1	73	65	21	19	1·1:1	10·2	0·4:1

* Mean values of 10 splits

Dr J. Mardon There is another possible explanation for Dr Marton's findings. In the press, the total pressure is made up of the hydraulic pressure and the compaction pressure of the sheet. The total pressure must remain the same as the sheet passes through the nip. The hydraulic pressure has to change: it is greatest on the bare roll side, least on the side of the sheet in contact with the felt. Therefore, the compaction pressure is greater on the side against the felt than that on the bare roll, so it may be that Dr Marton's sheets come more compacted on one side than on the other, owing to the pressure gradient in the nip.

Dr Marton Differential sheet compaction may have some effect that may be of more significance in unfilled sheets. Our conclusion is based on a quite detailed study of different variables with filled sheets. A most convincing one is the observation that, by increasing the specific surface area of the chosen filler (at constant filler load), we can increase the debonding effect and, correspondingly, the pick number strongly increases. This behaviour can hardly be explained by a compaction hypothesis.

Discussion

Dr J. Grant This is an interesting and new approach to a very old problem, but I am rather surprised that there is any problem with fluffing from eucalyptus furnishes. When I first started using eucalyptus, I suppose about 40 years ago, it was something of a problem, but much has happened in the meantime. For example, it has been known for many years that beating reduces the fluffing tendency; on the other hand, if you overdo it, you lose opacity. You may rectify this by going to the expense of adding titanium dioxide, but you still have the dimensional instability induced by beating, so there are limitations to the use of beating. On the other hand, by striking the right balance between beating, loading, furnish, etc., it is possible to produce papers that give no fluffing trouble whatsoever, even though they contain a high proportion of eucalyptus. If these expedients cannot be used, the machine size press remains; if this fails, quite the best method of removing the offending fines is to put the stuff through a Celleco or similar screen. I am puzzled therefore that the necessity for such an investigation should arise in this day and age.

Dr H. G. Higgins Our interest in this subject is not only for eucalyptus, but for tropical hardwoods as well. We commonly use eucalypts as reference pulps, in addition to our intrinsic interest in them. For young plantation-grown eucalypts, the problem of vessel picking may be of lesser significance than for the overmature eucalypts that are pulped in Australia and now in Japan and that have larger vessels than young wood. Furthermore, the high density eucalypts, which are not yet used for pulping, would be expected to give rise to enhanced picking problems, as indicated in our paper. We are of course aware of the various methods used to overcome vessel picking. Size press application and high consistency beating could also be mentioned.

Dr D. W. Clayton Do the dark streaks due to ellagic acid disappear easily on bleaching or do they pose a problem? I presume that, in any case, they increase the chemical consumption.

Dr H. G. Higgins Yes, the spots in unbleached paper have been correlated with the occurrence of ellagic acid in the wood. These materials tend to be removed by conventional bleaching processes. In pulping, they increase chemical consumption very substantially.