Reinforcing potential of different eucalypt: softwood blends during separate and co-PFI mill refining

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The reinforcement potential and optical properties of three market kraft pulps, two of New Zealand origin and a benchmark northern hemisphere pulp from interior British Columbia, Canada, were evaluated and compared following supplementation with a eucalypt market kraft pulp and refining. Eucalypt: softwood blends were investigated in the proportions of 100:0, 90:10, 80:20, 50:50 and 0:100, as were the effects of separate and co-refining employing a PFI laboratory refiner.

The influence of softwood fibre quality on handsheet property interrelationships decreased with increasing proportions of eucalypt fibre present in the blends. The tear – tensile relationships, or furnish reinforcement strength, of 80:20 eucalypt: softwood blends were roughly the same and independent of the origin or type of softwood fibres used. It was apparent that the tear – tensile strength relationships were generally the same for PFI mill separate and co-refined eucalypt: radiata pine softwood blends in all proportions, while the eucalypt: McKenzie blends tended to develop lower tear strengths for given tensile strengths with PFI mill co-refining. In contrast, handsheet optical properties of all eucalypt: softwood blends demonstrated similar trends, regardless of the refining regime.

Keywords

Reinforcing potential, refining, co-refining, kraft pulp, physical properties,optical properties, hardwood-softwood blends

The mechanical treatment, or refining, of fibres is an important step in the development of pulp furnishes for papermaking (*1*). The extent to which pulps are refined significantly influences the resultant fibre properties, and consequently the end products. Furthermore, the refining process has a critical effect on the formation and runnability of the paper machine. In general, the refining process produces a number of modifications to fibre morphology, such as fibre breakage or cutting, external fibrillation, secondary wall delamination, and altered collapsibility and flexibility. Several other processing factors, such as drying history, slushing regimes, stock concentration, pH, temperature, and pulping and bleaching significantly influence the degree of modifications induced by mechanical refining, as do inherent fibre characteristics including wood species, origin, age and chemical composition (*2*).

It is well recognised that paper properties are highly correlated to inherent fibre morphology, such as fibre length, fibre diameter and wall thickness. For example, the refining process effectively causes fibres of relatively low coarseness, consisting of thin cell walls, to readily collapse during pressing and drying, and are consequently highly suitable for fine paper production. In contrast, thick walled fibres, of higher coarseness, are more difficult to develop and consequently retain their intrinsic strength, and are more appropriate for some packaging grade materials and specialty products, such as fibre cement boards.

It has been shown that pulps originating from the interior region of British Columbia (Canada), eastern Canada and Scandinavia are more readily refined to a given strength and freeness than those from the southern USA (*3,4,5*). In contrast, radiata pine kraft pulps are of comparatively good strength but have intermediate refining requirements, the latter of which are markedly less than those of Southern pine but more than those of the Canadian pulps (*4*). Furthermore, the refining requirements and fibre quality of radiata pine pulps can vary significantly, a consequence primarily of the rapid growth of the wood. In an attempt to control uniformity and fibre quality, the New Zealand pulp and paper industry has adopted a segregation and monitoring regime for chips in the wood yard before they enter the digester. Consequently, categories of market kraft pulp have been established based on fibre length and coarseness, and they are ultimately utilised for different end-uses.

The aim of the present research was to investigate the refining response of radiata pine kraft pulps and pulp blends by characterising the physical, reinforcement and optical properties of eucalypt: softwood blends. The market kraft pulps included in the study are radiata pine pulps of low and medium coarseness, a benchmark pulp from the interior region of British Columbia, and a eucalypt pulp produced in Brazil. The effects of separate and co-refining of the softwood and hardwood pulps are assessed using a PFI laboratory mill. This work is a direct continuation of a comparable study in which similar pulps and blends were evaluated using an Escher Wyss refiner (*4,5*).

EXPERIMENTAL

Market pulp samples

Radiata pine market kraft pulps of low and medium coarseness were supplied by Carter Holt Harvey (Kinleith mill), Tokoroa New Zealand. These pulps are designated 'standard low' and 'standard medium', respectively.

The McKenzie mill of Fletcher Challenge Canada supplied the softwood pulp from the interior region of British Columbia. Pulp species composition was roughly 70:30 spruce: lodgepole pine. The McKenzie pulp is used as a benchmark since it is recognised by papermakers as being a leading softwood market pulp.

The eucalypt pulp from Brazil was reference material 8496 supplied by Aracruz Cellulose South America and distributed by National Institute of Standards and Technology, Standard Reference Materials Program, Building 202, Room 205, Gaithersburg, Maryland 20899, USA.

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Pulp processing and evaluation

The market kraft pulps were reslushed by tearing the lap pulp samples into thin pieces of less than 10 cm^2 and soaking overnight in distilled water. The soaked pieces were disintegrated at 1.2% stock concentration, for 75,000 revolutions using a British Standard disintegrator. Reslushed pulps were refined in the PFI mill in accordance with AS 1301. 209rp-89, employing an applied refining load of 3.4 N/mm. Pulps were refined at 10% stock concentration for 0, 500, 1000, 2000, 4000 and 8000 revolutions. Cut edges of whole-lap samples were excluded from the material used in accordance with AS 1301. 417s-92. Separate and co-refined pulps were produced using blends of eucalypt: softwood kraft pulp in proportions of 100:0, 90:10, 80:20, 50:50 and 0:100.

Handsheets were prepared and pulp physical evaluations made in accordance with relevant AS 1301 standard procedures. Physical evaluation data are reported on an oven-dried basis. Weighted average fibre length and fibre coarseness were determined using a Kajaani FS-200 instrument following TAPPI standard method T271 pm-91.

RESULTS AND DISCUSSION

Length, coarseness and numbers of fibres

The length weighted fibre lengths of the unrefined standard medium (2.46 mm) and McKenzie (2.49 mm) pulps were practically identical, while their coarseness values of 0.275 and 0.198 mg/m, respectively, were very different (Table 1). In contrast, the standard low pulp contained shorter fibres (2.14 mm) of intermediate coarseness (0.243 mg/m) when compared to those of the standard medium and McKenzie furnishes. As expected, the eucalypt fibres were roughly a third of the length and coarseness of the softwood fibres. Based on fibre length and coarseness, and a value of 100 fibres for the standard low furnish, the calculated relative numbers of fibres per unit mass of each pulp, and pulp blend, are as noted in Table 1. Generally, the differences in the relative numbers of fibres per unit mass were very small when considering the 50:50 and 80:20 eucalypt: softwood blends. However, when the unblended softwood pulps were examined, the numbers of fibres per unit mass were substantially lower for the standard medium than for either the standard low or McKenzie pulps. The proportion of standard medium fibres in the 80:20 eucalypt: radiata pine blend was about 2.2% (15 out of 701) while that of the eucalypt: McKenzie blend was approximately 3.0% (21 out of 707).

The effects of separate and mixed PFI mill refining on the length weighted fibre lengths of fibres and fibre blends are represented in Table 2. Briefly, it appeared that the fibre lengths were unchanged or slightly increased with both separate and co-refined PFI milling. It has previously been shown that fibres are normally straightened with PFI mill refining (*6*), which could account for the observed increased fibre lengths of several of the pulps and/or pulp blends. It is known that certain pulps develop more rapidly (in all refiners, including a PFI mill) than others, and that the presence of certain substances (i.e. carboxymethylcellulose, guar gum, starch) and/or fibre characteristics (i.e. fibre length, cell wall thickness) may retard or accelerate the refining effect (*7*). Since the refining conditions for all the current pulps were identical, and the fibre length of the McKenzie and the standard medium were very similar, it is likely that fibre coarseness, and indirectly the number of softwood fibres, was an influential factor(s) that affected the refining response. In contrast, the refining response of the standard low pulp was likely to be more related to the difference in fibre length, which has previously been shown to affect refining behaviour more so than any other fibre property (*7*).

Freeness development

It was apparent from the onset that the McKenzie pulp, which possesses smaller fibre diameter and lower coarseness fibres, had a predisposed lower furnish freeness, which consequently corresponds to better papermaking properties (Table 2). Figure 1 clearly demonstrates that the McKenzie pulp maintained this lower freeness throughout the entire refining regime, as compared to the radiata market kraft pulps. As expected, the hardwood furnish had a significantly lower pulp freeness when compared to those of the reinforcing softwood pulps (Fig. 1).

A comparison of tensile strengths at a given freeness clearly indicated that the McKenzie pulp refined to a lower target freeness more rapidly than either of the radiata pine furnishes, and subsequently produced sheets that demonstrated higher tensile strength at a given freeness. It was also shown that both pine furnishes were very similar with respect to their freeness – tensile strength relationships (Fig. 2), despite their clear differences in fibre length and coarseness.

Table 1
Length weighted fibre lengths, coarseness values and calculated relative number of fibres per unit mass for the unrefined eucalypt: softwood pulp blends.

Pulp	Blend (%)	Length weighted fibre length (mm)	Fibre coarseness (mg/m)	Relative number of fibres per unit mass*
Eucalypt	100:0	0.74	0.082	857
Eucalypt: standard low	0:100	2.14	0.243	100
	50:50			478
	80:20			706
Eucalypt: standard medium	0:100	2.46	0.275	77
	50:50			466
	80:20			701
Eucalypt: McKenzie	0:100	2.49	0.198	105
	50:50			480
	80:20			707

* Calculated.

Table 2
Fibre length and pulp freeness of eucalypt: softwood blends after separate and co-refining in a PFI mill.

Blend (%)	Refining	Revs	Eucalypt: Standard Low		Eucalypt: Standard Medium		Eucalypt: McKenzie	
			LWL* (mm)	Freeness (mL)	LWL* (mm)	Freeness (mL)	LWL* (mm)	Freeness (mL)
0:100	Separate	0	2.14	726	2.46	726	2.49	624
		500	2.29	689	2.58	733	2.52	640
		1000	2.28	676	2.54	714	2.54	625
		2000	2.30	643	2.62	695	2.53	–
		4000	2.28	549	2.58	602	2.53	466
		8000	2.25	314	2.46	349	2.50	276
50:50	Separate	0	1.05	561	1.12	597	1.18	558
		500	1.05	564	1.19	618	—	573
		1000	1.13	546	1.17	587	1.18	534
		2000	1.16	466	1.17	495	1.26	463
		4000	1.19	314	1.17	351	1.20	318
		8000	1.19	138	1.12	120	1.23	124
50:50	Co-refined	0	1.12	491	1.12	552	1.23	500
		500	–	527	–	606	–	512
		1000	–	507	–	53	–	487
		2000	–	422	–	463	–	405
		4000	–	284	–	303	–	259
		8000	–	110	–	122	–	107
80:20	Separate	0	0.85	537	0.84	524	0.88	523
		500	0.88	501	0.89	456	0.91	439
		1000	0.88	462	0.89	446	0.91	400
		2000	0.89	3332	0.90	349	0.91	313
		4000	0.91	195	0.88	198	0.90	190
		8000	0.87	77	0.84	53	0.88	70
80:20	Co-refined	0	0.86	420	0.86	451	0.90	421
		500	0.86	495	0.90	541	0.89	498
		1000	0.88	427	0.89	488	0.91	449
		2000	0.88	398	0.89	380	0.91	390
		4000	0.89	232	0.89	248	0.91	233
		8000	0.91	83	0.84	83	0.90	77
90:10	Separate	0	0.79	463	0.78	433	0.82	503
		500	0.81	463	0.80	509	0.85	489
		1000	0.82	407	0.81	474	0.84	432
		2000	0.83	343	0.81	359	0.84	351
		4000	0.83	215	0.81	194	0.84	229
		8000	0.82	80	0.77	71	0.82	70
90:10	Co-refined	0	0.79	402	0.79	426	0.80	396
		500	–	424	–	419	–	419
		1000	–	382	–	369	–	352
		4000	–	157	–	175	–	192
		8000	–	65	–	47	–	56
100:0	Separate	0	0.74	449				
		500	0.76	424				
		1000	0.76	318				
		2000	0.77	305				
		4000	0.76	203				
		8000	0.73	51				

*LWL = Length Weighted Fibre Length

Tensile strength – apparent density relationships

When tensile strengths were evaluated employing sheet density as a basis for comparison, it was apparent that the standard medium and McKenzie pulps had very similar tensile strength – apparent density relationships following various degrees of PFI mill refining (Fig. 3). However, the McKenzie pulp developed the highest absolute tensile strengths for a given amount of PFI refining, concurring with previous trends observed with Escher Wyss refining (*4,5*).

The standard low pulp produced handsheets of higher apparent density (low bulk) compared with the eucalypt and other softwood pulps. It was also apparent that PFI mill refining of eucalypt kraft pulp can generate handsheets of slightly higher apparent densities relative to those of the McKenzie and standard medium pulps, for a given tensile strength.

Handsheet properties following separate and co-refining

Clear differences were observed when pulps of corresponding blends were mixed and compared prior to or following refining (independently refined and blended vs. co-refined). For example, market pulps that were unrefined and

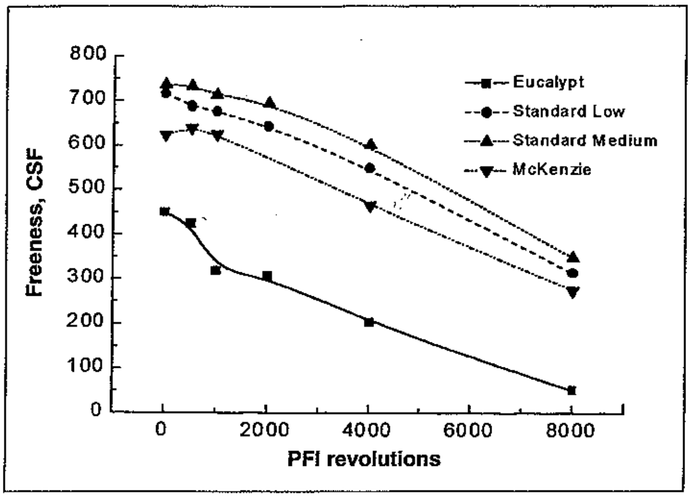

Fig. 1 Pulp freeness development with PFI refining.

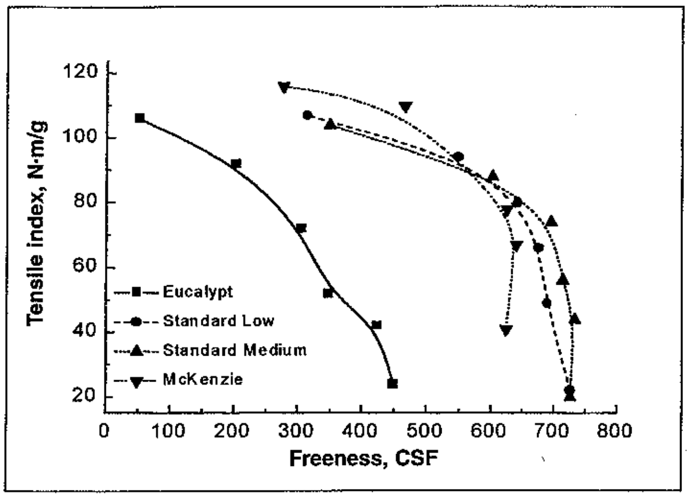

Fig. 2 Freeness – tensile strength relationships of PFI refined furnishes.

blended before disintegration prior to PFI mill co-refining show concurrent decreased blend freeness (up to 100 CSF) and increased apparent densities, by greater than 20 kg/m^3 (Fig. 4). Apparently, the standard laboratory re-wetting and disintegration procedures can cause the freeness and apparent density of dry lap eucalypt: softwood blends to be modified. However, these changes occur with the web tensile strengths being essentially unchanged by the re-wetting and disintegration processes (Fig. 5). Furthermore, the effect occurred with all eucalypt: softwood blends, irrespective of the softwood pulp employed.

Reinforcement potential – tear/tensile relationships

It has been demonstrated that tear – tensile strength relationships are indicative of pulp reinforcement potential and web runnability on papermachines (*3-5,8,9*). Therefore, the current investigation used this interrelationship as a measure of the reinforcement characteristics and overall sheet strength of the three softwood pulps within the eucalypt: softwood blends.

As expected, the tear strength at a given tensile strength increased as eucalypt: softwood blend proportions increased from zero to 100 percent for both separate and co-refining (Fig. 6,7). For the unblended softwood and hardwood pulps typical tear – tensile strength relationships were observed with PFI refining (*4,5*). Tear strengths increased with refining to maximum values of approximately 10 mN·m^2/g for the eucalypt pulp, while the softwood pulps decreased to minimal values of about 9 mN·m^2/g. Typical tear index peaks, at tensile index values of 40 to 50 N·m/g, are observed with the softwood pulps (*9*).

Separate refining

The standard medium radiata pine furnish with its relatively long and coarse fibres produced a slightly higher overall tear strength for a given tensile strength (Fig. 6,7). The shorter length and lower coarseness characteristics of the standard low showed improved formation (based on apparent density) when compared to the corresponding standard medium handsheets. However, based on tear – tensile interrelationships, the McKenzie pulp had comparable properties to those developed by the standard medium (Fig. 6,7). These findings corroborate earlier results, from the investigation of similar blends and proportions following different Escher Wyss refining intensities (*4,5,10*). Seth (*11*) has also recently reported similar findings.

The influence of different softwood fibre qualities decreased with increasing proportions of hardwood included in a blend. At 80:20 and 90:10 eucalypt: softwood proportions, the consolidated web reinforcement properties were roughly the same for the standard medium, standard low and McKenzie blends (Fig. 6,7). It appeared that in the 50:50 eucalypt: softwood blends the tear – tensile properties were directly related to the nature of the softwood component, while the tensile properties alone were a function of both the eucalypt and the softwood components. It is clear that the reinforcing strength of the McKenzie and standard medium blends were higher than that of the standard low blend, in accordance with trends previously obtained with separate Escher-Wyss refining (*4,5*).

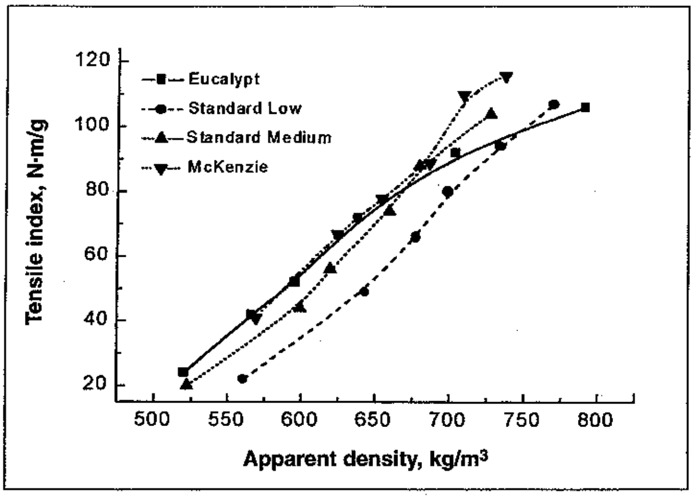

Fig. 3 Apparent density – tensile strength relationships of PFI refined furnishes.

PFI mill co-refining

The tear – tensile strength relationships are generally the same for PFI mill separate and co-refined eucalypt:radiata

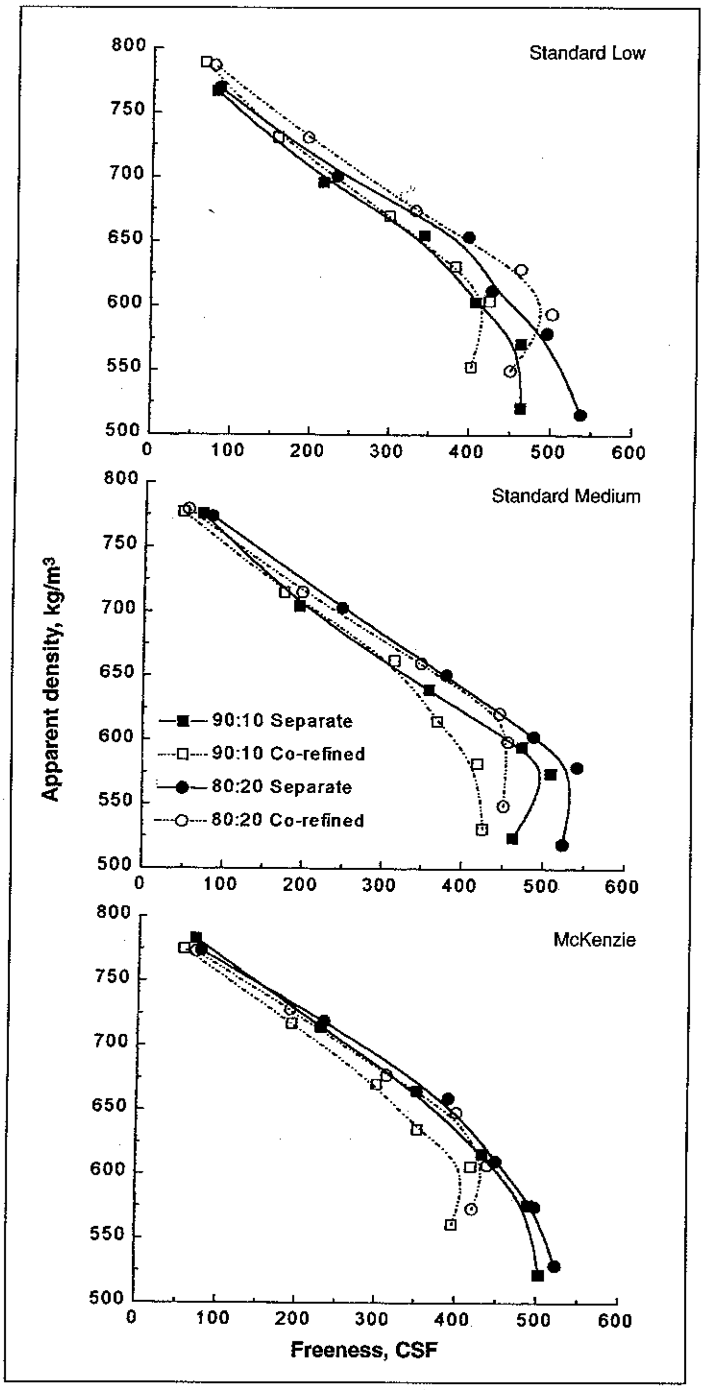

Fig. 4 Freeness vs. apparent density of different eucalypt: softwood pulp blends during separate and co-PFI mill refining.

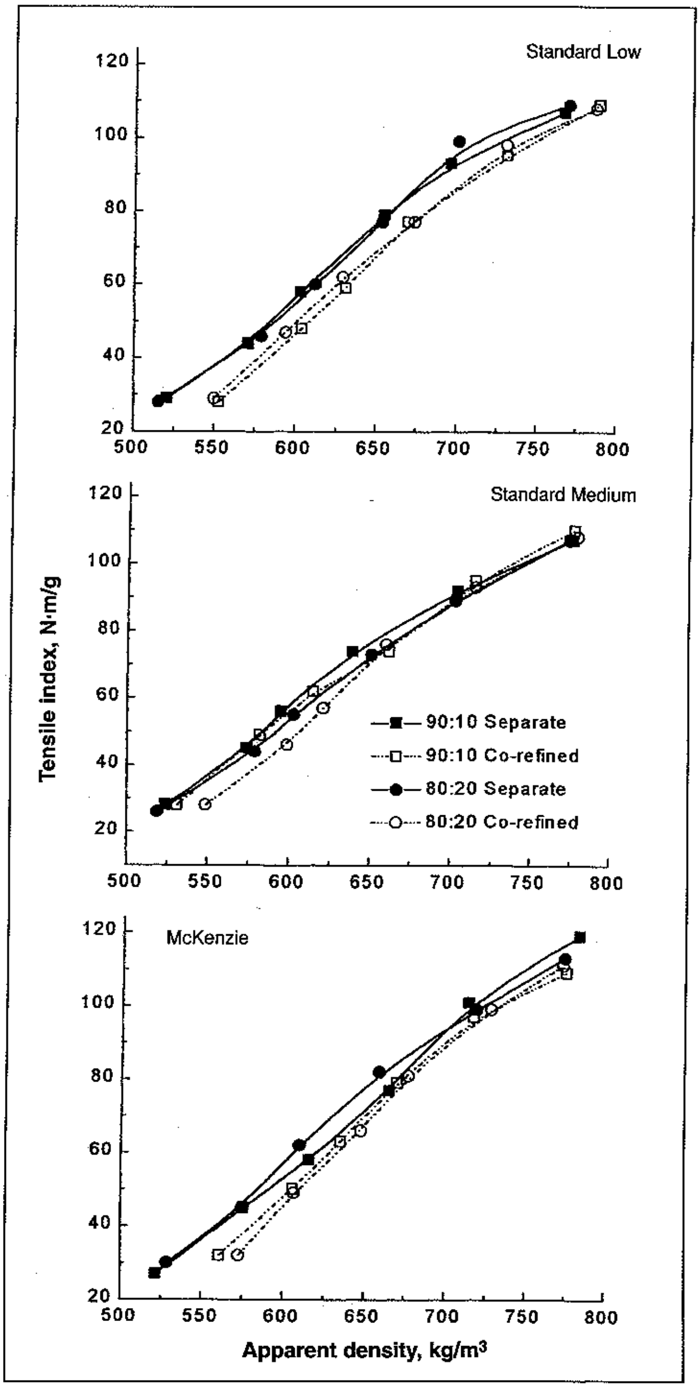

Fig. 5 Tensile index vs. apparent density of different eucalypt: softwood pulp blends during separate and co- PFI mill refining.

softwood blends in the proportions of 50:50, 80:20 and 90:10, while the eucalypt: McKenzie blends tend to develop lower tear strengths for given tensile strengths with PFI mill co-refining (Fig. 7). For example, at the 80:20 proportions, the tear values at 50 N·m/g tensile strength were approximately 10.75, 11 and 12 mN·m2/g, respectively, for the low, medium and McKenzie pulps following separate refining, while during co-refining the corresponding values of tear index were 10.75, 10.75 and 10.25 mN·m2/g, respectively.

The high stock concentration at which PFI mill refining takes place probably accounts for the similar reinforcement properties obtained with the softwood pulps during separate and co-refining. At stock concentrations of 10 per cent the numbers of fibre-to-fibre contacts and interactions are high, and numbers of fibre-to-tackle contacts relatively low. Hence, the effects of refining are envisaged as being developed primarily through the pressing and rubbing against one another of hardwood and/or softwood fibres and flocs (*12,13*). Thus, PFI mill refining is perceived to be relatively homogeneous and generally independent of whether individual blend components are separate or co-refined. The converse holds with Escher Wyss refining, at 3.5 per cent stock concentration, where the softwood component of a blend is refined more heavily than the eucalypt component (*1*). Previously, it has been shown that these pulps develop differently when subject to Escher Wyss refining (*4,5*), particularly in freeness development. Briefly, for pulps blended after separate refining, only the softwood component of

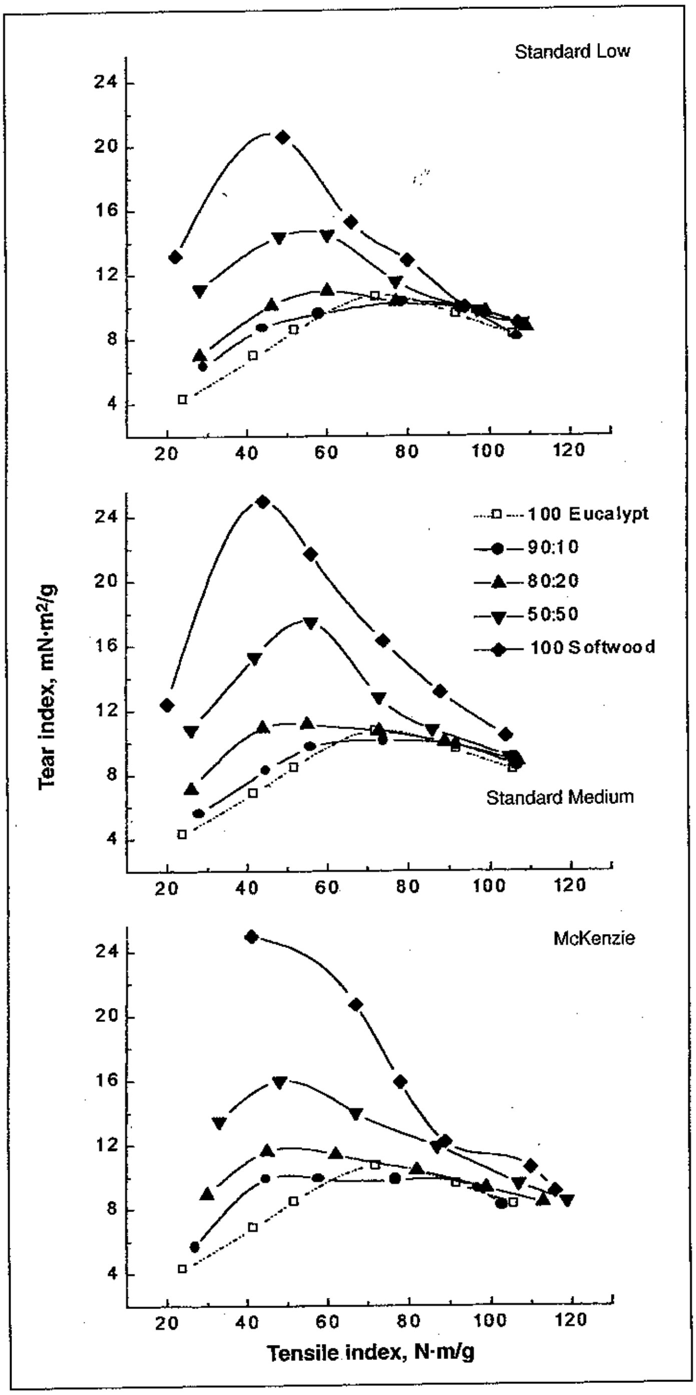

Fig. 6 Eucalypt: softwood blend reinforcement strengths following separate PFI mill refining.

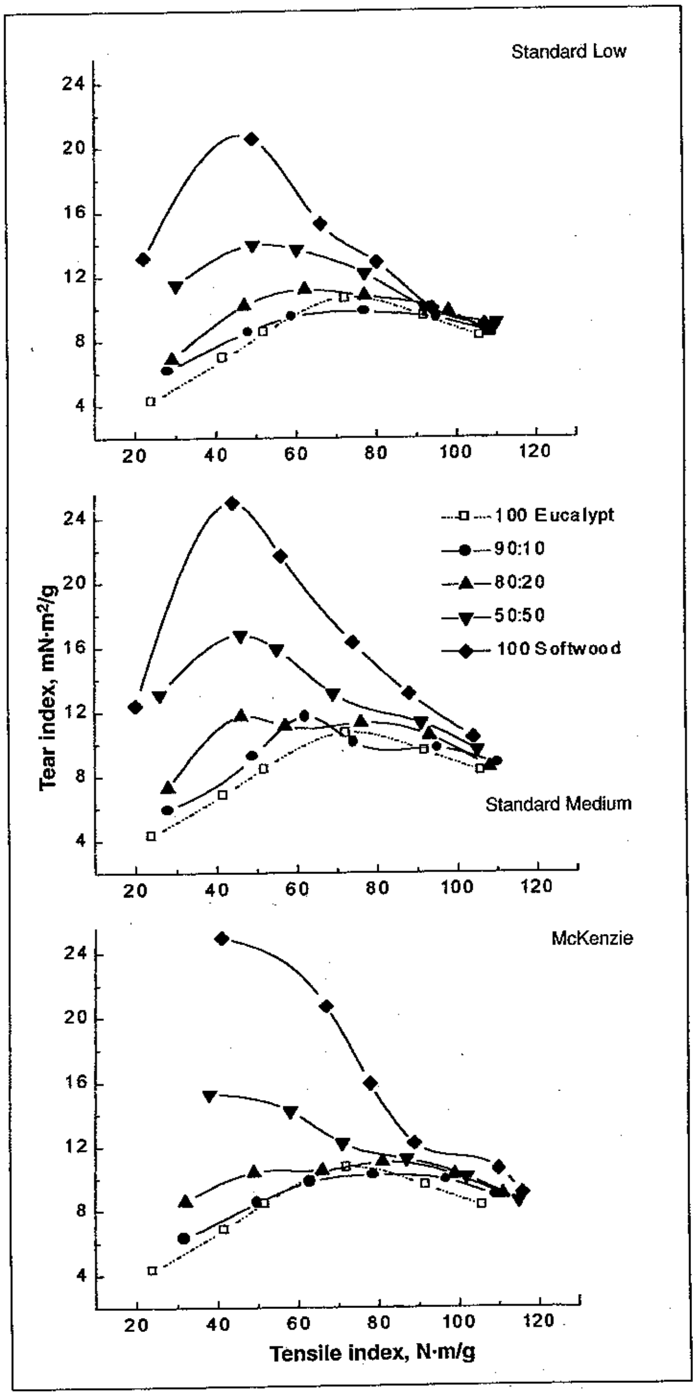

Fig. 7 Eucalypt: softwood blend reinforcement strengths following co-PFI mill refining.

a blend contributes to the shortening of fibres since the eucalypt fibre lengths were unchanged during refining at a specific edge load of 0.5 Ws/m. Comparatively, during co-refining with the Escher Wyss, fibres were shortened only slightly when processed at the low specific edge load, while at higher specific edge load (1.5 Ws/m) showed a 21% reduction in fibre length. When the unblended eucalypt fibres were refined at the higher specific edge load alone, they were shortened by 11%, suggesting that the majority of the refining load is carried by the softwood component during Escher Wyss co-refining (*4,5*).

Optical properties

At a given apparent density, the eucalypt pulp had by far the highest light scattering potential followed by the softwood pulps in the order McKenzie and standard low, which demonstrate similar light scattering, and then the standard medium (Fig. 8,9). The similarities in the light scattering potential of the McKenzie and the standard low pulps are likely related to a combination of approximately the same numbers of fibres and the surface topographies of the resultant handsheets produced by these fibres. Similarities in the latter characteristic are likely related to the higher packing densities and therefore bonding of the relatively short and wide fibres exhibited by the standard low pulp, while the McKenzie fibres possess a greater number of light scattering surfaces as a result of their long and slender morphology.

In general, the light scattering coefficients of eucalypt: softwood pulp blends decreased with increasing propor-

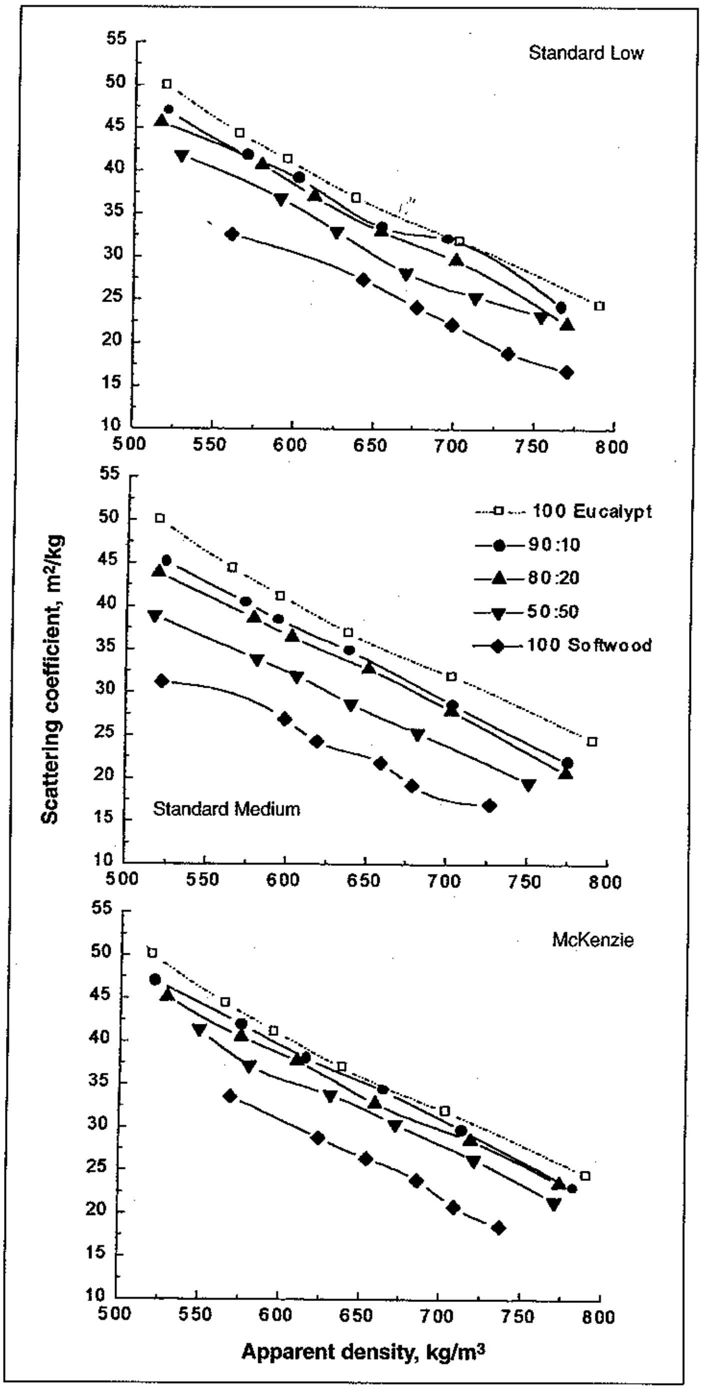

Fig. 8 Light scattering – apparent density relationship of eucalypt: softwood blends following separate PFI mill refining.

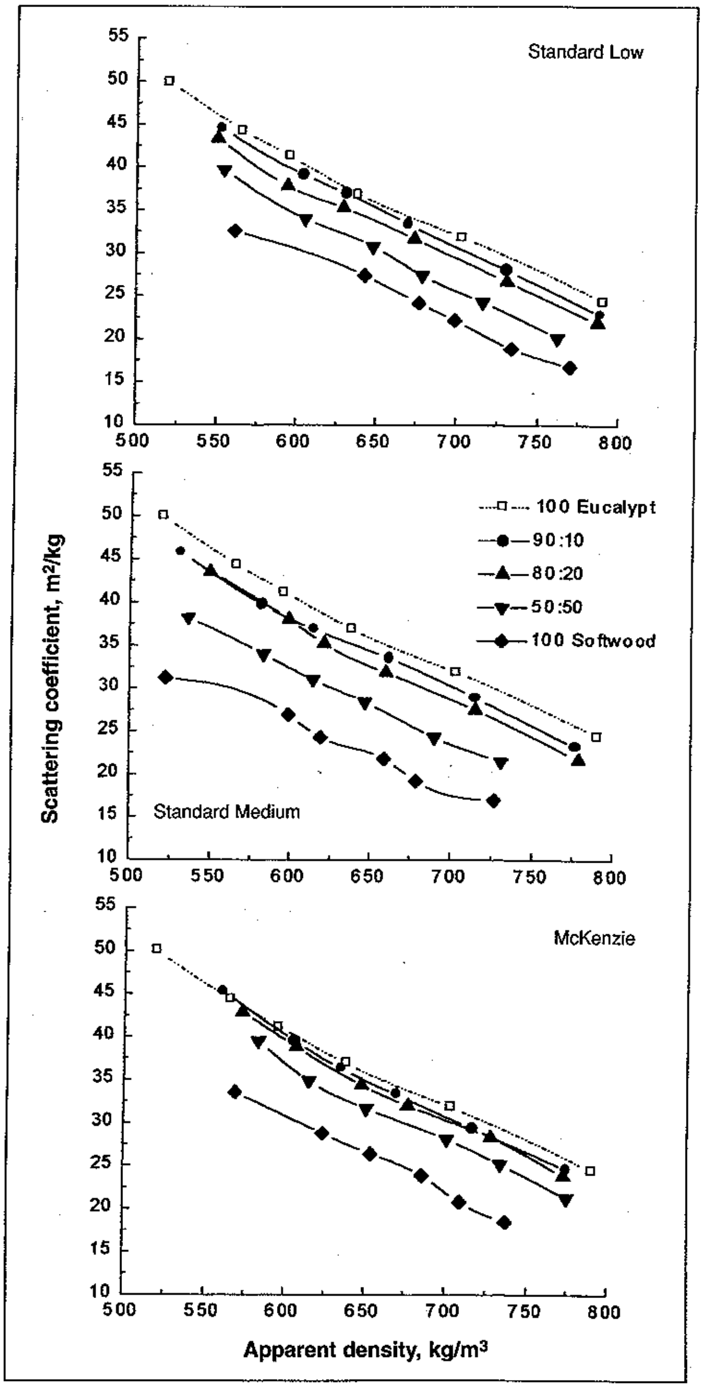

Fig. 9 Light scattering – apparent density relationship of eucalypt: softwood blends following co- PFI mill refining.

tions of softwood fibres included in a furnish. The McKenzie blends had marginally higher scattering coefficient at a given apparent density than those of the standard low and standard medium blends. On the whole, the optical characteristics were reflected in the unrefined apparent density versus light scattering values, and maintained proportionally throughout the refining process (Fig. 8,9).

As well, the light scattering – apparent density relationships were generally the same with PFI mill separate and co-refining of 50:50, 80:20 and 90:10 eucalypt: softwood blends (Fig. 8,9), as was previously observed with the related handsheet strength properties. Light scattering coefficients were certainly not increased with co-refining, which is the case with Escher Wyss refining (*4,5*). The similar light scattering values of separate and co-refined eucalypt: softwood blends may be explained by the homogeneity of PFI mill processing and high numbers of fibre-to-fibre contacts and interactions, as discussed previously.

CONCLUSIONS

In general, the influence of softwood fibre quality differences on handsheet property interrelationships decreased with decreasing proportions in eucalypt: softwood pulp blends. The tensile strength – apparent density relations for the eucalypt and softwood pulps were roughly the same, except for the standard low pulp, which produced sheets of higher apparent densities for a given tensile strength when compared to the other furnishes.

For eucalypt: softwood blend proportions equal to, or greater than 80:20, the tear – tensile relationships or furnish reinforcement strengths were roughly the same and independent of the origin or type of softwood used. Thus, quality differences among softwood fibres had minimal effects on the web reinforcement properties of 80:20 eucalypt: softwood blends in nominal 60 g/m^2 handsheets. Pulps refined separately before blending had a tendency to exhibit slightly higher reinforcement strengths than those that were blended before co-refining, as has previously been observed when evaluated using other refiners, such as the Escher Wyss refiner.

The optical properties, as indicated by light scattering coefficient, were similar for all three eucalypt: softwood blends, independent of the nature of refining (separate and co-refining).

During PFI mill refining, both separate and co-refining treatments give similar, but not identical web reinforcement and optical properties. In contrast, Escher Wyss refined treatments can give very different web properties. Many of the pulp quality differences observed with Escher Wyss and PFI mill refining (both separate and co-refining) can be explained by pulp re-wetting and disintegration conditions, refining stock concentrations, and numbers of fibre-to-fibre and fibre-to-tackle contacts and interactions occurring during the fibre processing. Furthermore, mechanistically the two refiners affect fibre morphology differently, which subsequently alters the observed freenesses. Therefore, caution should be employed when attempting to correlate PFI-refined furnish sheet properties based on pulp freeness with those after industrial-type refining.

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REFERENCES

(1) Baker, C. F. – Good practice for refining the types of fiber found in modern paper furnishes, *Tappi J.* **78**(2):147 (1995).

(2) Lumiainen, J. and Oy, S. D. V. – Refining of ECF and TCF bleached scandinavian softwood kraft pulps under the same conditions, *Pap. Puu* **79**(2): 109 (1997).

(3) Kibblewhite, R. P. – Effect of refined softwood: eucalypt pulp mixtures on paper properties, *Transactions of the 10th Fundamental Research Symposium – Products of papermaking*, Oxford, UK, p.127 (1993).

(4) Kibblewhite, R. P. – Refining requirements of softwood and eucalypt kraft market pulps and blends, *Appita J.* **47**(5):375 (1994).

(5) Kibblewhite, R. P. – Reinforcement and optical properties of separate and co-refined softwood and eucalypt market kraft pulps, *Appita J.* **47**(2):149 (1994).

(6) Kibblewhite, R. P. and Brookes, D. – Factors which influence the wet web strength of commercial pulps, *Appita J.* **28**(4):227 (1975).

(7) Watson, A. J. and Phillips, F. H. - Beating characteristics of the PFI mill. III. Observations relating to the beating mechanism, *Appita J.* **18**(3):84 (1964).

(8) Kibblewhite, R. P. and Bawden, A. D. – Blends of extreme high and low coarseness radiata pine pulps – fibre and handsheet properties, *Appita J.* **43**(3):199 (1990).

(9) Kibblewhite, R. P. and Shelbourne, C. J. A. – Genetic selection of trees with designer fibres for different paper and pulp grades, *Transactions of the 11th Fundamental Research Symposium – Fundamental of Papermaking Materials*, Cambridge, UK, p.439 (1997).

(10) Brindley, C. L. and Kibblewhite, R. P. – Comparison of refining response of eucalypt and a mixed hardwood pulp and their blends with softwood, *Appita J.* **49**(1):37 (1996).

(11) Seth, R. S. – Beating and refining response of some reinforcement pulps, *TAPPI J.* **82**(3):147 (1999).

(12) Kibblewhite, R. P. – Effects of beating on radiata pine kraft properties: effects of beaters, *Appita J.* **27**(6):418 (1974).

(13) McKenzie, A. W. and Prosser, N. A. – Beating action of a PFI mill, *Appita J.* **34**(4):293 (1981).

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