Comparison of refining response of eucalypt and a mixed hardwood pulp and their blends with softwood

CATHERINE L. BRINDLEY* and R. PAUL KIBBLEWHITE†

SUMMARY

Different bleached market kraft pulps respond to refining in different ways. The response to refining of a mixed hardwood pulp, alone and in mixed hardwood:softwood blends, is examined and compared with that of a eucalypt pulp and pulp blends. The mixed hardwood pulp responds differently to refining, and has inferior strength and optical properties, compared with the eucalypt pulp. Mixed hardwood: softwood 80:20 blends have similar properties regardless of the fibre quality of the softwood component, as found previously for eucalypt:softwood blends. Mixed hardwood:softwood blends are weaker than corresponding eucalypt:softwood blends, but have equivalent optical properties. Mixed hardwood:softwood blends have freeness and strength properties similarly developed whether separately refined or co-refined at 0.5 W.s/m specific edge load. Co-refining at 1.5 W.s/m gave inferior results. Eucalypt: softwood blends have freeness and strength properties better developed after separate refining, with co-refining at 1.5 W.s/m giving better results than 0.5 W.s/m.

Different bleached market kraft pulps can respond to refining in different ways (1,2,3). The primary objective of the present research is to identify optimum refining conditions and treatments for processing radiata pine kraft pulps and pulp blends. Previous work has examined the refining requirement, freeness, strength and optical properties of three softwood market pulps and eucalypt: softwood pulp blends (1,2,3).

This paper examines the response to refining of a mixed hardwood pulp, alone and in mixed hardwood:softwood blends, and compares it to that of a eucalypt pulp and pulp blends. Softwood pulps used in the blends include radiata pine pulps of low and medium coarseness and a benchmark pulp from the interior region of British Columbia. Effects of separate and co-refining are assessed using a laboratory scale Escher Wyss conical refiner, a unit which is considered to give results indicative of commercial scale refining operations (4).

EXPERIMENTAL

Pulp origins

The mixed hardwood bleached market kraft pulp originated from Mitsubishi, Japan and was supplied by Caxton Paper Ltd (now Carter Holt Harvey). Percentage species compositions are beech 48, willow/ poplar 14, cherry 9. alder 8, maple 7, oak 4, magnolia 3, birch 3, others 4.

The eucalypt pulp was supplied by Aracruz Cellulose S.A. and was the same as that used in a previous study (1). Softwood pulps used in blending were radiata pine bleached market kraft pulps of medium and low coarseness and softwood pulp supplied by the McKenzie mill of Fletcher Challenge Canada, as detailed in the previous paper (1).

Pulp processing and evaluation

The Escher Wyss laboratory scale conical refiner, of NZFP Pulp and Paper Limited (now Carter Holt Harvey Pulp and Paper), was used to process the pulps as follows: stock concentration 3.5%, refining speed 1500 r/min, specific edge loads 0.5, 1.5 and 2.5 W.s/m (mixed hardwood pulp only), and refining energies 0, 40, 80, 120, 160, and, 200 kWh/t.

For softwood and mixed hardwood pulps which were refined separately before blending, respective specific edge loads were 3.0 W.s/m and 0.5 W.s/m. Pulps were blended in mixed hardwood:softwood proportions 0:100, 50:50, 80:20 and 100:0. The eucalypt pulp was refined at 0.5 W.s/m only and not blended with softwood pulps in this study.

Softwood and hardwood pulps were blended after Escher Wyss processing following a previously described method (1) except that the stock concentration of each Escher Wyss run was determined on the 80 kWh/t refined sample.

For the co-refined samples, whole lap samples were blended before disintegration and refined at 0.5 and 1.5 W.s/m. Pulps were blended in mixed hardwood:softwood proportions of 80:20 only.

Handsheets were prepared and pulp physical evaluations made in accordance with Appita standard procedures. Physical evaluation data are reported on o.d. bases.

Fibre dimension measurement

Relative weighted average fibre length and fibre coarseness were determined using a Kajaani FS-200 instrument and standard PAPRO procedures.

Unrefined and refined fibres were dehydrated, embedded and sectioned, and the cross-section dimensions of fibre thickness, width, wall area, and wall thickness were measured using a previously described method (5). Slurry samples were diluted to stock concentrations of < 0.1% to minimize the possibility of refined fibre wall structural organizations changing with storage time. Dehydration and embedding of diluted slurry samples were commenced the day after processing.

The product of fibre width and fibre thickness represents the fibre cross-section area. The ratio width:thickness can give an indication of fibre collapse since the greater the width and the lower the thickness of a fibre cross-section, the greater is the extent of fibre collapse.

Relative numbers of fibres per unit mass were calculated using the reciprocal of the product 'fibre coarseness x fibre length'. A base value of 100 fibres per unit mass was taken for the Std low radiata pine pulp with relative values being calculated for all other furnishes using principles of proportionality.

RESULTS

Eucalypt and mixed hardwood fibre properties

Unrefined length-weighted fibre lengths of the mixed hardwood and eucalypt pulps are approximately the same (Table 1). The coarseness of the mixed hardwood pulp is higher than that of the eucalypt pulp, and therefore there are fewer fibres per unit mass in the mixed hardwood pulp (Table 1). Although the length-weighted lengths are similar, the fibre length population distributions, weighted by length, are different for the eucalypt and mixed hardwood pulps (Fig. 1), as expected (6). The mixed hardwood pulp has a much greater percentage of fines – around 2% weighted by length, compared with 0.2% for the eucalypt pulp. The mixed hardwood pulp has a broader distribution of fibre lengths, and thus has more fibres of length

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* Science Technician, Member Appita.
† Research Scientist, Member Appita.
Papro New Zealand, New Zealand Forest Research Institute Ltd., Private Bag 3020, Rotorua, New Zealand

Paper presented at 48th Annual General Conference, Melbourne 1994.

greater than 1.5 mm, than the eucalypt pulp.

The eucalypt pulp fibres were shortened by 9% after refining for 200 kWh/t at 0.5 W.s/m (Table 2), and mixed hardwood pulp fibres were shortened by 14%. More shortening of the mixed hardwood fibres occurs at higher specific edge loads, being 21% at 1.5 W.s/m and 25% at 2.5 W.s/m as expected (1).

Fibre width, thickness and overall cross-section area (width x thickness) are greater for the mixed hardwood fibres than for the eucalypt fibres, as are wall area and wall thickness (Table 2). With refining, mixed hardwood fibre dimensions increase rapidly then gradually decrease. Eucalypt fibre dimensions tend to increase with refining, but to a lesser extent than the initial increase of the corresponding mixed hardwood fibre dimensions.

As with the length-weighted length distributions (Fig. 1), the cross-section area (width x thickness) and wall area distributions for the unrefined mixed hardwood fibres are broader than for the eucalypt fibres (Fig. 2,3), indicating a greater spread of fibre sizes and less pulp uniformity in the mixed hardwood furnish. There are more large fibres of cross-section area greater than 100 µm2, and of wall area greater than 80 µm2, in the mixed hardwood pulp.

Eucalypt and mixed hardwood strength and optical properties

Handsheet properties of eucalypt and mixed hardwood pulps and blends are published in a PAPRO report (7) and can be made available upon request.

The eucalypt and mixed hardwood pulps show similar trends in response to refining at different specific edge loads (7). Treatment at 0.5 W.s/m is most effective, and at 2.5 W.s/m least effective, in developing tensile strength (Fig. 4). This is more marked in the

Table 1
Length-weighted length, coarseness, and relative numbers of fibres per unit mass of unrefined pulps

Pulp	Fibre length mm	Fibre coarseness mg/m	Percentage fines by number	No. of fibres by unit mass
Eucalypt	0.76	0.075	13	940
Mixed hardwood	0.78	0.096	39	715
Std low	2.26	0.237	24	100
Std medium	2.50	0.271	31	79
McKenzie	2.49	0.176	27	122

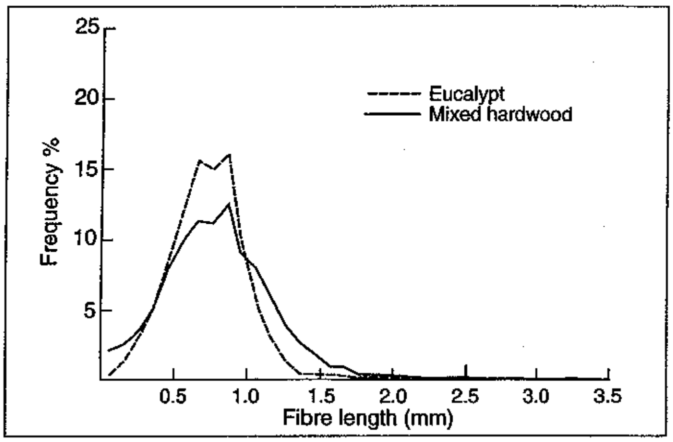

Fig. 1 **Population distributions for unrefined mixed hardwood and eucalypt fibre length-weighted lengths**

Table 2
Fibre length and cross-section dimensions

Pulp	Refining energy kWh/t	Specific edge load W.s/m	Fibre length mm	FS200 coarseness mg/m	Fibre width µm	Fibre thickness µm	Width x thickness µm²	Wall area µm²	Wall thickness µm	Width/ thickness
Eucalypt	0	0.5	0.76	.075	13.5	6.6	89	59.8	2.36	2.17
	40		0.78		13.9	7.6	107	69.6	2.45	1.92
	80		0.76		13.4	7.4	101	65.9	2.41	1.89
	120		0.72		13.9	7.4	105	68.4	2.46	1.96
	160		0.69		13.6	7.4	102	66.7	2.39	1.92
	200		0.69		13.4	7.7	105	68.6	2.42	1.85
Mixed Hardwood	0	0.5	0.78	.096	14.4	7.1	104	67.9	2.42	2.15
	40		0.76		15.1	8.3	131	84.6	2.68	1.86
	80		0.75		14.9	8.0	121	78.2	2.58	1.99
	120		0.70		13.7	8.1	114	76.4	2.78	1.77
	160		0.68		14.0	8.1	116	75.4	2.58	1.80
	200		0.66		13.4	7.6	104	67.4	2.42	1.84
Least significant difference					0.9	0.4	10	6.2	0.13	0.15

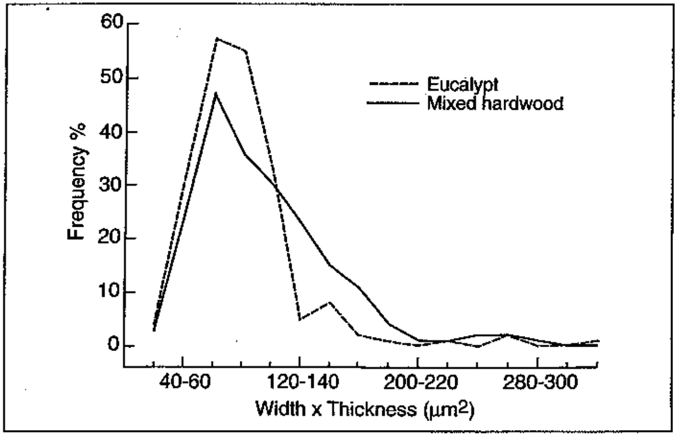

Fig. 2 **Population distributions for unrefined mixed hardwood and eucalypt fibre cross-section area dimensions**

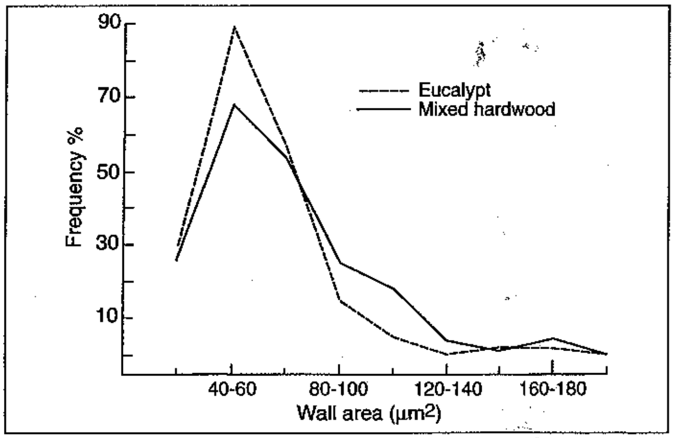

Fig. 3 **Population distributions for unrefined mixed hardwood and eucalypt fibre wall area dimensions**

mixed hardwood furnish, where the difference between tensile strengths after treatment at the three specific edge loads is much greater than for the eucalypt pulp.

The mixed hardwood pulp has a lower unrefined tensile strength than the eucalypt pulp for a given specific edge load (Fig. 4). The eucalypt pulp develops, with refining, higher tensile strengths for given freeness values than the mixed hardwood furnish (7)

Changes in specific edge load influence the apparent density or bulk of mixed hardwood pulp more than eucalypt pulp (7). The apparent density of the mixed hardwood pulp is increased most by refining at 0.5 W.s/m. For given tensile strengths, the eucalypt pulp develops high tearing resistance when compared with the mixed hardwood pulp. Refining at a specific edge load of 0.5 W.s/m is most effective in developing tearing resistance and tensile strength.

Light scattering coefficients are higher for the eucalypt than for the mixed hardwood pulp particularly with tensile strength as the basis of comparison (2,7). Light scattering coefficients are reduced most by refining at 0.5 W.s/m. Once again, the mixed hardwood furnish is more affected than the eucalypt pulp by changes in specific edge load.

Mixed hardwood:softwood pulp blends

Fibre lengths and fibre shortening: For pulps blended 80:20 (mixed hardwood:softwood) after separate refining, length-weighted fibre lengths are shortened on average by 19% (7). The 50:50 blends are shortened on average by 23 %. The softwood component of the separately refined blends, treated at 3 W.s/m, suffers more shortening (24% (1)) than does the mixed hardwood component (14%), refined at 0.5 W.s/m.

When co-refined, length-weighted fibre lengths of mixed hardwood: softwood blends are shortened on average by 21% at 0.5 W.s/m and 30% at 1.5 W.s/m, with the McKenzie blends suffering most shortening at both specific edge loads (7). These results indicate considerably more fibre shortening for mixed hardwood: softwood blends than occurred for the eucalypt:softwood blend fibres in the previous study (1).

Pulp freeness, refining energy and tensile strength relations: Freeness-tensile relations are the same for the Std medium, Std low and McKenzie 80:20 mixed hardwood:softwood blends (Fig. 5). For the 50:50 blend, on the other hand, freeness-tensile strength relations are somewhat different depending on the softwood component and overall trends are similar to those obtained with corresponding eucalypt:softwood blends (1). The 50:50 mixed hardwood: McKenzie blend has the highest freeness for given tensile strengths when compared with corresponding Std medium and Std low blends.

The tensile strengths of 80:20 mixed hardwood:softwood blends are similar when pulps are refined separately at 3 W.s/m (softwood) and 0.5 W.s/m (mixed hardwood), or co-refined at 0.5 W.s/m specific edge load (Fig. 6) (7). Co-refining at 1.5 W.s/m is less effective in developing tensile strengths. These effects contrast with those of eucalypt:softwood blends where separate refining is clearly most effective in developing tensile strength, and co-refining at 1.5 W.s/m is more effective than treatment at 0.5 W.s/m. Furthermore, tensile strengths of 80:20 eucalypt:softwood blends are always substantially greater than those of corresponding mixed hardwood: softwood blends.

Freeness-tensile strength relations are essentially the same for the separate and co-refined mixed hardwood: softwood blends (Fig. 7) (7). For the eucalypt:softwood blends, however, separate refining is more effective in developing tensile strength.

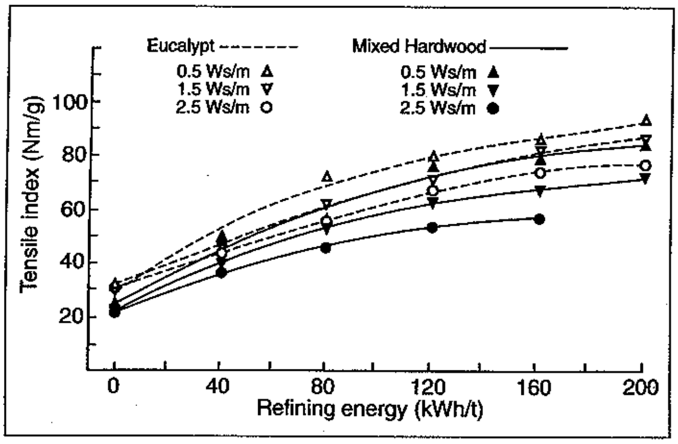

Fig. 4 **Tensile strength/refining energy for mixed hardwood and eucalypt pulps refined at three specific edge loads**

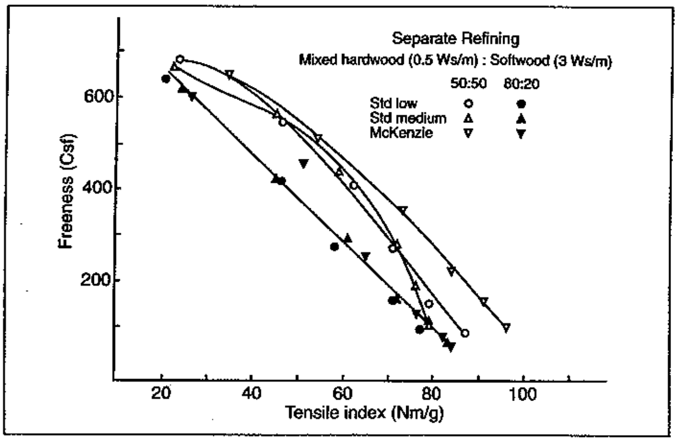

Fig. 5 **Pulp freeness-tensile strength for separately refined mixed hardwood:softwood blends**

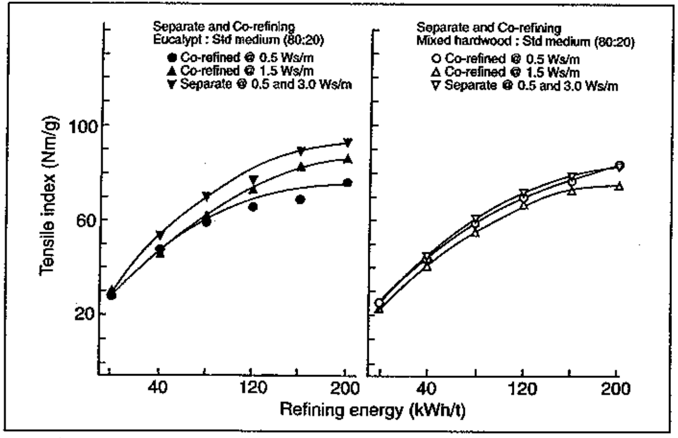

Fig. 6 **Tensile strength/refining energy for eucalypt:Std medium and mixed hardwood:Std medium blends – separate and co-refined.**

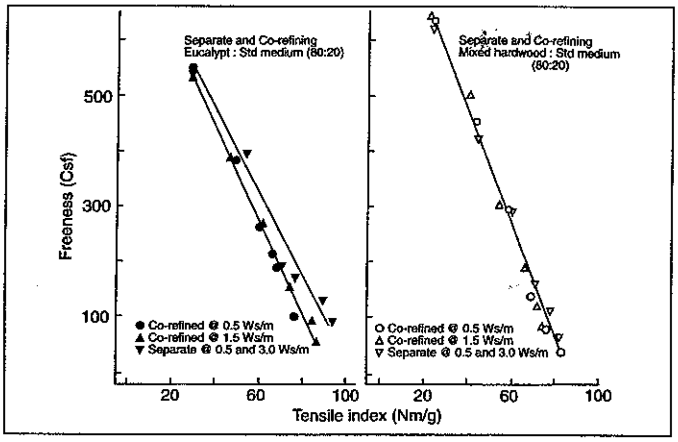

Fig. 7 **Pulp freeness-tensile strength for eucalypt:Std medium and mixed hardwood:Std medium blends – separate and co-refined**

Reinforcement properties: For eucalypt:softwood blends, tearing resistance at a given tensile strength decreases with increasing eucalypt proportions (2). The same trend occurs with the mixed hardwood blends but is more marked, as the mixed hardwood pulp by itself has markedly lower tearing resistance than the eucalypt pulp (Fig. 8,9) (7). As might be expected, the influence of softwood fibre quality decreases with decreasing softwood proportions in a pulp blend (1). In the 80:20 mixed hardwood: softwood blends, the tear-tensile relationships are very similar between softwoods, even more so than are the 80:20 eucalypt:softwood blends. For the 50:50 mixed hardwood: softwood blends, the Std medium furnish has the highest tearing resistance, but the differences between the blends of the three softwoods are small.

Co-refining is only marginally less effective than separate refining in developing the tearing resistance of 80:20 mixed hardwood:softwood blends (Fig. 10) (7). This effect is markedly less than that obtained with corresponding eucalypt:softwood blends (1).

Optical properties: Light scattering coefficients at given handsheet tensile strengths decrease with increasing proportions of softwood included in the mixed hardwood: softwood blends (Fig. 11). This is less marked with the mixed hardwood than with the eucalypt blends, as the light scattering coefficient of the mixed hardwood pulp before blending is lower than that of the eucalypt, and blending of mixed hardwood with 20% softwood does not greatly lower the light scattering coefficient further (Fig. 12) (7). Hence the differences in light scattering potential of eucalypt and mixed hardwood pulps are greatly reduced when blended with 20 or 50% softwood fibre. The 80:20 and 50:50 mixed hardwood:softwood blends have light scattering properties equivalent to those of corresponding eucalypt: softwood blends. Again, the influence of softwood fibre quality is reduced as increasing proportions of mixed hardwood fibre are included in the furnish, and at the 80:20 (and 50:50) level the three different mixed hardwood:softwood blends have similar light scattering properties, closer even than those of the equivalent eucalypt:softwood blends.

For 80:20 mixed hardwood: softwood blends, light scattering coefficients are marginally higher with co-refining at 0.5 W.s/m than with separate refining, at energy inputs of 80 kWh/t (tensile index of 60 N.m/g) or more (Fig. 13). This effect is independent of softwood fibre type since similar values are obtained with the Std medium, Std low and McKenzie mixed hardwood:softwood blends (7).

DISCUSSION

Mixed hardwood and eucalypt pulp properties

Fibre dimensions: Fibre length and cross-section dimensions were in accordance with previous findings (6). The mixed hardwood fibres are on average thicker-walled, coarser and overall larger than the eucalypt fibres (Table 2). The eucalypt pulp is more uniform in that fibres are mostly of similar length, cross-section area (width x thickness) and wall area (Fig. 2,3). The mixed hardwood fibres have broader population distributions and are therefore less uniform, with more coarse fibres than the eucalypt pulp.

The fibre dimensions of the two pulps respond to refining in different ways. The increase in eucalypt fibre dimensions with refining is relatively small. This implies that fibre walls are not necessarily greatly swollen or obviously delaminated, consistent with that found previously (3,8). In contrast, the mixed hardwood fibres, in the initial stages of refining, are rapidly rewetted and become uncollapsed, and fibre walls are expanded and become delaminated.

Specific edge load effects: Treatment at a low specific edge load (0.5 W.s/m) is most effective of the

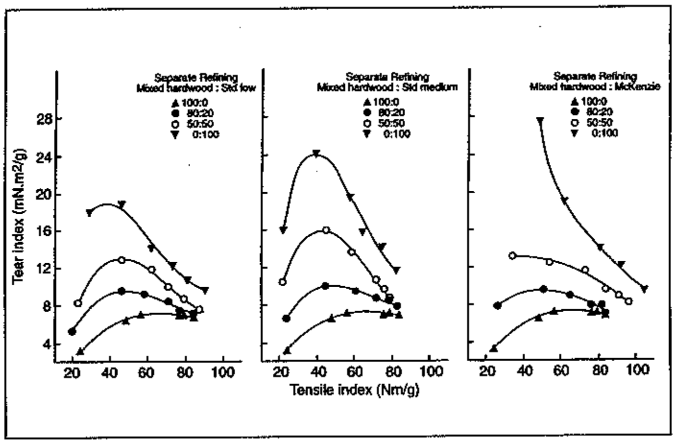

Fig. 8 Reinforcement strengths for mixed hardwood:softwood blends – separate refined.

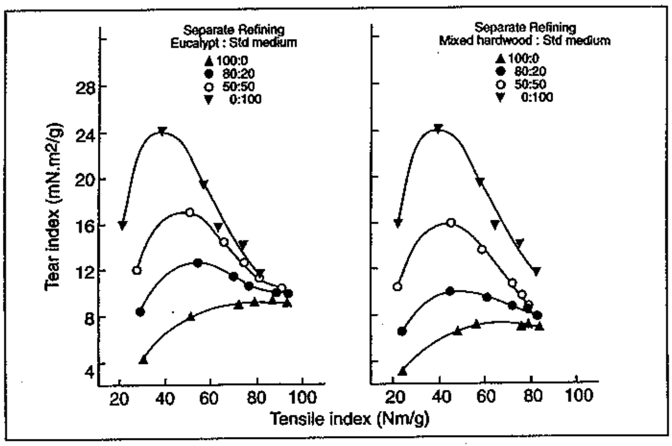

Fig. 9 Reinforcement strengths for eucalypt:Std medium and mixed hardwood:Std medium blends – separate refined.

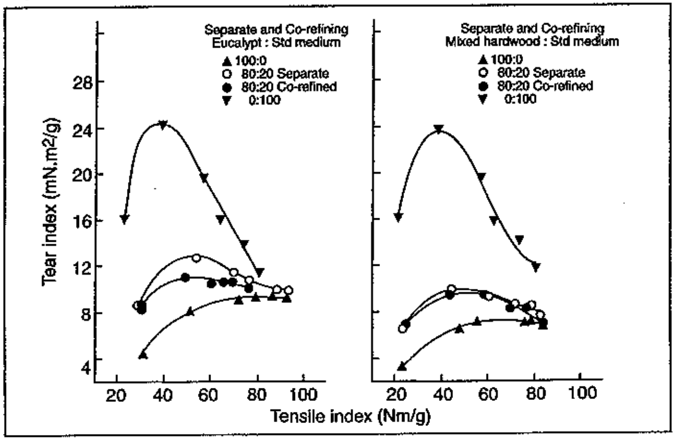

Fig. 10 Reinforcement strengths for eucalypt:Std medium and mixed hardwood:Std medium blends – separate and co-refined.

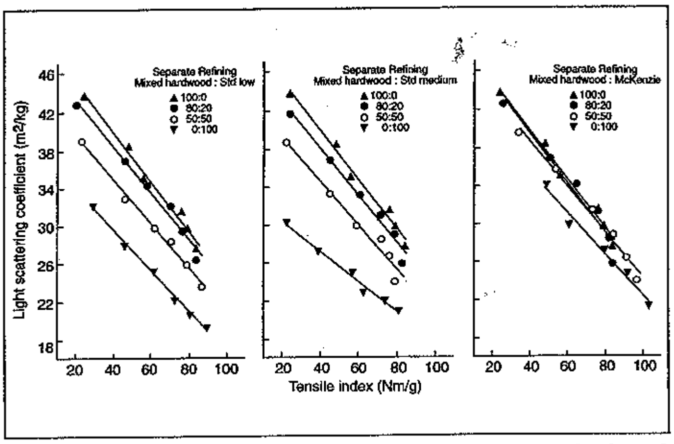

Fig. 11 Light scattering/tensile strength for mixed hardwood:softwood blends – separate refined.

specific edge loads trialled, in developing tearing resistance and tensile strength, increasing apparent density or decreasing bulk, and reducing pulp freeness, in both the mixed hardwood and eucalypt pulps (7), as expected (2).

Strength and optical properties: The mixed hardwood pulp when refined alone has poorer strength properties than the eucalypt pulp (7). This is explained by fewer fibres per unit mass, the lower pulp uniformity and the higher fines content of the mixed hardwood pulp. The lower number of fibres per unit mass results in less fibre to fibre bonding. Particulate fines can influence bonding but not necessarily add much strength to a well refined pulp.

The inferior light scattering properties of the mixed hardwood pulp (7) are related to the greater quantity of fines and the lower number of fibres. A pulp with fewer fibres per unit mass gives a sheet with fewer but larger voids between fibres, which scatter light less effectively than would many, smaller voids. A high number of fines can reduce light scattering coefficient by bonding on the fibre surfaces, and/or filling voids with well bonded fine material.

Mixed hardwood:softwood pulp blends

Separate refining: Freeness-tensile relations of the three mixed hardwood:softwood blends are very similar when separately or co-refined (Fig. 7) (7). As expected, this effect is greatest with the 80:20 blends. At this level, freeness-tensile relations are independent of softwood fibre type, as found previously with eucalypt:softwood blends (1). With separate and co-refining, freeness-tensile strength regressions for the three mixed hardwood:softwood blends are similar and very much closer one to another than those for corresponding eucalypt:softwood blends (1).

The influence of softwood pulp fibre quality decreases with increasing proportions of mixed hardwood included in a pulp blend, as expected (1,2). For the three separately refined 80:20 mixed hardwood:softwood blends, reinforcement and tear-tensile properties are similar (Fig. 8,9) (7), more so than those of the eucalypt:softwood blends (1,2). At the 50:50 level, mixed hardwood:Std low and mixed hardwood:McKenzie blends have very similar tear-tensile curves, while the Std medium blend has a higher tear fora given tensile at the 40 kWh/t refining level. This trend is the same as that obtained with corresponding eucalypt: softwood blends, although actual tear values are higher for the eucalypt furnishes (2). This is to be expected, given the inferior strength properties of the unblended mixed hardwood pulp relative to the eucalypt pulp.

Light scattering coefficients for 50:50 blends of mixed hardwood:Std low and Std medium are virtually the same, with the mixed hardwood: McKenzie blend having a slightly higher value for given tensile strengths (Fig 11). At the 80:20 level, light scattering coefficients are very similar for the three mixed hardwood:softwood blends. The light scattering properties of the mixed hardwood:softwood blends are virtually the same as those of the eucalypt:softwood blends, even at the 80:20 level, despite the marked difference in light scattering coefficients of the two hardwood pulps refined alone (Fig. 12) (7).

Co-refining – specific edge load effects: For the mixed hardwood: softwood blends, co-refining at 0.5 W.s/m gives a lower freeness and higher tensile strength than co-refining at 1.5 W.s/m (Fig. 6,7) (7). For the eucalypt:softwood blends however, co-refining at 1.5 W.s/m gives the lower freeness and the higher tensile strength (1). This implies a fundamental difference in the way the fibres are affected by refining.

For the eucalypt:softwood blends, the softwood component can be considered to take a disproportionate amount of the refining load in co-refining, and hence a specific edge load of 1.5 W.s/m has a greater effect on tensile development and freeness reduction than an edge load of 0.5 W.s/m, as would be expected in softwood pulp (3). At the 1.5 W.s/m edge load, therefore, softwood fibre walls can be expected to be selectively expanded, delaminated, wetted, and made flexible (3). Also, some fibrillation of fibre surfaces would occur and increase the bonding potential of the blend.

The mixed hardwood:softwood blends, on the other hand, contain a large quantity of primary fines originating from the mixed hardwood pulp (Table 1, Fig. 1,2)(6). Maximum surface development of softwood fibres, and maximum overall development of hardwood fibres, can be expected with the low intensity 0.5 W.s/m refining treatment (3). Hence, maximum retention of the mixed hardwood fines can be expected through entanglement following refining at 0.5 W.s/m. Such an explanation accounts for the low freeness and high bonding properties selectively developed with co-refining the mixed hardwood:softwood blends at a low specific edge load (0.5 W.s/m) (Fig. 6). Furthermore, less fibre shortening occurs at 0.5 than at 1.5 W.s/m.

Separate and co-refining effects: The difference in pulp blend properties between separate (softwood 3 W.s/m and hardwood 0.5 W.s/m) and co-refined (0.5 W.s/m) mixed hardwood:softwood blends is smaller than that obtained with corresponding eucalypt:softwood blends (Fig. 10) (7). The reinforcement strength reduction obtained with co-refined eucalypt:softwood blends is attributed to the less than optimum specific edge loads (0.5 and 1.5 W.s/m) for refining of the softwood fibres in the blend, causing them not to be maximally developed as they would be at 3 W.s/m (3). In the mixed hardwood:softwood blends co-refined at 0.5 W.s/m, the increase in fines retention appears to negate this effect by increasing furnish bonding potential, which could explain why blends co-refined at 0.5 W.s/m have as good strength properties as those which are separately refined. Co-refining at 1.5 W.s/m gives lower strength properties than separate refining, as with the eucalypt:softwood blends.

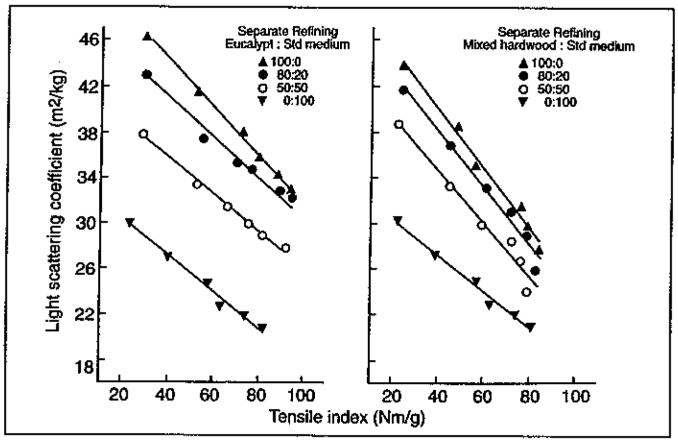

Fig. 12 **Light scattering/tensile strength for eucalypt:Std medium and mixed hardwood:Std medium blends – separate refined.**

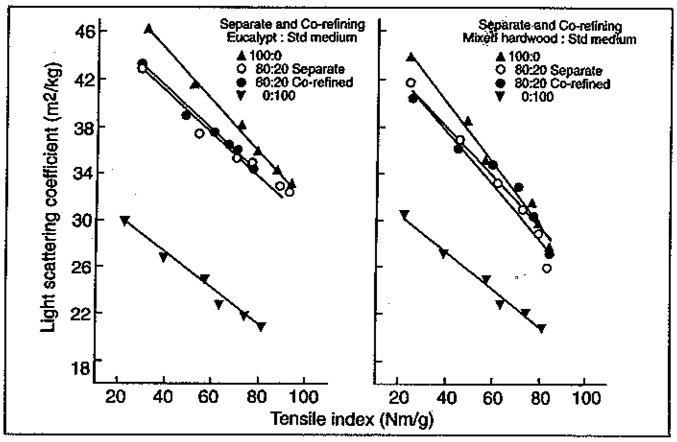

Fig. 13 **Light scattering/tensile strength for eucalypt:Std medium and mixed hardwood:Std medium blends – separate and co-refined.**

Loss of fibre length during refining is similar for co-refined blends at 0.5 W.s/m and the equivalent separately refined blends, and this applies to both eucalypt and mixed hardwood:softwood blends (7) (1). Fibre shortening is greater at 1.5 W.s/m than at 0.5 W.s/m, for all co-refined blends. Greater loss of fibre length occurs in the mixed hardwood:softwood blends than in the eucalypt:softwood blends. This may explain, in part, why the mixed hardwood:softwood blends have poorer reinforcement properties than the corresponding eucalypt:softwood blends.

CONCLUSIONS

The mixed hardwood pulp evaluated in this study has very different properties from the eucalypt pulp evaluated previously (1,2,3). When refined alone, the mixed hardwood pulp has poorer strength and optical properties, and a greater refining energy requirement, than the eucalypt pulp. These differences are explained by the different fibre characteristics in the unrefined pulps.

Mixed hardwood pulp properties are optimized by refining at 0.5 W.s/m, as are eucalypt pulp properties.

When blended with softwood pulps, the mixed hardwood pulp shows the same trends that were found with the eucalypt pulp. The effect of softwood fibre quality on freeness, and handsheet strength or optical properties is greatly reduced when softwoods are blended with 50% mixed hardwood, and eliminated when blended with 80% mixed hardwood pulp.

The mixed hardwood:softwood blends have lower tear for a given tensile than the eucalypt:softwood blends.

Although the optical properties of the mixed hardwood pulp are inferior to those of the eucalypt pulp, this is not reflected in the optical properties of the mixed hardwood:softwood blends. The scattering coefficients for both the 50:50 and the 80:20 mixed hardwood: softwood blends are as good as those of the corresponding eucalypt:softwood blends.

The mixed hardwood:softwood blends respond differently from the corresponding eucalypt:softwood blends, to co-refining at a low specific edge load. While tensile strengths of eucalypt:softwood blends are optimally developed when co-refined at 1.5 W.s/m, tensile strengths of mixed hardwood:softwood blends are optimized when co-refining is at 0.5 W.s/m. This difference is attributed to the larger proportion of fines in the mixed hardwood pulp, and increased retention of these fines after co-refining at low specific edge loads.

With eucalypt:softwood blends, separate refining gives greater tensile strength for a given energy input, and greater tear for a given tensile, than co-refining (2). With mixed hardwood: softwood blends, co-refining at 0.5 W.s/m gives the same tensile-energy and tear-tensile relations as separate refining.

ACKNOWLEDGEMENTS

The technical assistance of Jacqueline Lee, Cornelia Hughes and Julia Jackman is gratefully acknowledged.

The supply of pulp from the Kinleith mill of NZFP (now Carter Holt Harvey) Pulp and Paper, the McKenzie mill of Fletcher Challenge Canada, and Caxton Paper (now Carter Holt Harvey Tissue), are also gratefully acknowledged. The availability of the Escher Wyss laboratory refiner of NZFP (CHH) Pulp and Paper is also acknowledged.

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Revised manuscript received for publication 14.8.95