Research paper

Effects of Fiber Morphological Characteristics and Refining on Handsheet Properties

Yuan-Shing Perng,[1)] Eugene I-Chen Wang,[2,5)] Yin-Li Cheng,[3)] Yu-Chun Chen[4)]

【Summary】

Under a fixed wet end chemical additive regime, pulp fibers of different morphological characteristics, including 2 softwood pulps of northern softwood and radiata pine, and 3 hardwood pulps of eucalyptus, mixed Indonesian hardwoods, and acacia underwent different degrees of pulp refining and then were used individually or as a blend (1 softwood to 1 hardwood pulp) to form handsheets. The handsheet bulk, water absorption, air permeability, and dry and wet opacities properties were then compared and correlated to the fiber morphological indicators such as fiber length, coarseness, and population in order to provide a reference for furnish blending to make specialty papers and other applications.

The experiment on the individual pulp fibers indicated that along with increasing degrees of refining, the fiber population increased proportionally, pulp freeness and fiber lengths changed in an inverse manner, while fiber coarseness changed irregularly. The blended furnishes, on the other hand, indicated that along with increases in the hardwood pulp proportions, the freeness, fiber lengths, and coarseness changed in an inverse trend, whereas the fiber population also increased. Thus, it is feasible to use refining and blending of softwood and hardwood pulps to adjust the stock that meets the required freeness and fiber morphological properties for paper machines.

Analysis of handsheets formed from individual pulps indicated that paper bulk and both dry and wet opacities decreased with an increased degree of pulp refining and were negatively correlated. Water absorption, and air permeability, on the other hand, increased with increasing pulp refining and exhibited positive correlations. The bulk and opacity of the hardwood pulps were higher than those of the softwood pulps, whereas the water absorption and air permeability values were higher than those of the hardwood pulps. The blended furnish study indicated that along with increasing hardwood pulp proportions, the paper bulk of Indonesian hardwoods pulp containing furnishes increased proportionally, while those of eucalyptus and acacia pulps containing furnishes

[1)] Department of Environmental Engineering, Dayeh University, 168 Xuefu Rd., Datsuen, Changhwa 51591, Taiwan. 大葉大學環工系，51591彰化縣大村鄉學府路168號。

[2)] Division of Wood Cellulose, Taiwan Forestry Research Institute, 53 Nanhai Rd., Taipei 10066, Taiwan. 行政院農委會林業試驗所木材纖維系，10066台北市南海路53號。

[3)] Department of Environmental Resources Management, Overseas Chinese Institute of Technology, 100 Chiaokuang Rd., Taichung 40721, Taiwan. 40721僑光技術學院環境資源管理系，台中市僑光路100號。

[4)] Kemira Taiwan Co., Ltd., 237, Sungchiang Rd., Taipei 10482, Taiwan. 10482台灣凱蜜拉公司，台北市松江路237號8樓。

[5)] Corresponding author, e-mail:iwang@tfri.gov.tw 通訊作者。

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showed negative correlations. Water absorption and air permeability values were negatively correlated to the hardwood pulp proportions, whereas opacities showed positive correlations. In addition, paper bulk and water absorption were positively correlated with the fiber coarseness (except for the Indonesian hardwoods), Relationships between the paper air permeability value and fiber coarseness and populations were furnish-dependent; while there was a positive correlation between paper opacities and fiber populations (except for the Indonesian hardwoods). There was a linear correlation between the pulp blend ratio and handsheet opacity. Hence, the opacity of a blended paper was derived from the opacities of the individual softwood and hardwood fibers.

Key words: fiber morphological properties, refining, bulk, water absorption, air permeability, opacity.

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研究報告

纖維形態及鍊漿對於手抄紙性質的影響

彭元興[1] 王益真[2,5] 鄭殷立[3] 陳毓鈞[4]

摘 要

本研究目的為在固定濕端內添化學藥品條件下，應用不同纖維形態的漂白化學木漿(北方針葉樹及放射松2種；尤加利漿、印尼雜木漿及相思木3種)，在不同鍊漿程度下，個別纖維及針葉/闊葉纖維混合配料，來探討對於手抄紙嵩度、吸水度、透氣度、乾/濕不透明度的影響，期能做為抄造特殊紙的配料及應用條件選用的參考。纖維形態指標以纖維長度、粗細度及纖維分布為代表。

個別纖維實驗顯示隨著鍊漿程度的增加，纖維分佈與鍊漿程度成正相關性，游離度及纖維長度則呈現負相關性，粗細度呈現不規則現象。混合配料實驗顯示，隨著闊葉樹漿配比增加，游離度、纖維長度與粗細度呈負相關性，纖維分布呈正相關性。可以藉由鍊漿程度及針葉/闊葉木漿配比，來調整配料達到抄紙機需求的游離度及纖維形態性質。

個別纖維組手抄紙實驗顯示，嵩度及不透明度(乾/濕)隨著鍊漿程度而下降，呈負相關性，吸水度、透氣度值隨著鍊漿程度而上升，呈正相關性。闊葉樹漿組的嵩度、不透明度高於針葉樹漿組。針葉樹漿組的吸水度、透氣度值高於闊葉樹漿組。混合配料組手抄紙實驗顯示，隨著闊葉樹漿比例提高，印尼雜木組嵩度呈正相關性，尤加利組及相思木組呈負相關性，吸水度及透氣度值呈負相關性，不透明度呈正相關性。嵩度及吸水度與粗細度呈正相關性(印尼雜木組除外)，透氣度與粗細度及纖維分布的關係隨漿料組合而異，不透明度與纖維分布呈正相關性。

關鍵詞：鍊漿、纖維形態性質、嵩度、吸水度、透氣度、不透明度。

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INTRODUCTION

Along with an increase in secondary fiber use and a trend toward lighter grammage of paper products, increasing the paper bulk and opacity while maintaining paper quality has become a goal which paper companies are striving to achieve. An annual report of the Japan Paper Association cited a case wherein through optimization of raw materials and the papermaking process, the bulk of wood-free book paper produced increased from 1.18 to1.67 cm^3 g^{-1}, and for medium grade book/text paper, even 2.22~2.86 cm^3 g^{-1} was achieved (Anon 2004).

Demands of the dry/wet opacities, air resistance, and water absorption by specialty papers differ depending on their applications. It is necessary to select suitable pulp blends to meet the requirements of customers (Hillman 1998). Greaseproof papers, on the other hand, require a smooth surface and opaqueness in both wet and dry conditions (Perng and Wang 2004b). Fruit-shading bag papers require them to be opaque when both dry and wet to prevent pecking by birds. Water absorption is needed for household papers; in addition, décor paper, saturated kraft, and laminated base paper boards all need high water absorption. Masking tape needs high opacity (Stephenson 1999).

Complex factors influence a paper's bulk, opacity (dry/wet), air permeability, and water absorption; these mainly include the fiber morphology, pulping process, fillers, papermaking parameters, etc. (Bristow and Kolseth 1986, Smook 1992, Scott and Abbott 1995, Danielweicz and Surma-Slusarska, 2004). Bleached chemithermomechanical pulp (BCTMP) can effectively enhance the bulk and opacity of paper, but it also causes yellowing of the paper, leading to lower brightness and quality (Perng et al. 2007). In recent years, there are reports of using surfactants to increase the paper bulk and commercial applications (Poffenberger and Jenny 1996, Ikuta et al. 2000, Takahashi 2000, Takahashi et al. 2000, Asakura and Isogai 2003). A mica mineral, sericite, was also found to act as a functional filler capable of stabilizing wet end conditions and increasing paper bulk (Perng and Wang 2004a, Perng et al. 2008).

Pulp fibers from different tree species are often characterized using parameters such as fiber length, coarseness, fiber population, etc. Lengths of fibers are influenced by the tree species, growth conditions, position within the stem, and methods of mechanical treatments. Typical coniferous pulp fibers have lengths of 1.8~2.5 mm, and hardwood fibers of 0.7~1.1 mm. The definition of coarseness is the product of the fiber cell wall thickness and peripheral length of the fiber, expressed as the mass per unit length with typical units of mg m^{-1} or mg km^{-1}. Coarseness is influenced by fiber width and cell wall thickness. Typical coniferous pulp fibers have widths of 25~50 μm, cell wall thicknesses of 3~8 μm, and coarseness of 0.15~0.35 mg m^{-1}. Typical hardwood pulp fibers, on the other hand, have widths of 10~35 μm, cell wall thicknesses of 2~5 μm, and coarseness values of 0.07~0.135 mg m^{-1}. Definition of the fiber population is the number of fibers per unit mass, and is commonly expressed as 10^6 fibers g^{-1}. The physical significance of the fiber population is the areal value for light scattering or the number of holes that can be filled. Typical coniferous pulp fibers have (1.0~2.5)$\times 10^6$ fibers g^{-1}, while hardwood pulp fibers have (10.0~15.0)$\times 10^6$ fibers g^{-1} (Hillman 1998).

The purpose of this study was to investigate the effects of different fiber morphological characteristics (coniferous and hardwood pulps) and different degrees of refining on the handsheet bulk, water absorption, air resistance, and opacity (both dry and wet conditions) properties while keeping the wet-end chemical regimes constant.

MATERIALS AND METHODS

Materials

The 5 experimental pulps studied were bleached northern softwoods kraft pulp (long fiber, Douglas fir 5%, lodgepole pine 45~50%, white spruce 45-50%, Prince George Mill, Canfor, Canada), bleached radiata pine kraft pulp (long fiber, Arauco, Chile), bleached eucalyptus kraft pulp (short fiber, probably a mixture of *Eucalyptus glubules* and *E. niten*, Arauco, Chile), bleached acacia kraft pulp (short fiber, P.T. Tel, Indonesia), and bleached mixed Indonesian hardwood kraft pulp (short fiber, Riau, Indonesia).

The wet-end chemical regimes simulated a typical paper mill sequence of addition and dosages. These were a wet-strength agent (Kymene 557, 0.4%, Hercules Co.), low-molecular- weight strong cationic coagulant polymer (Nalco 7607, 0.3%), alkyl ketene dimmer (AKD) sizing agent (Hercon 76, 0.30%, Hercules Co.), high-molecular-weight anionic flocculent polymer (Nalco 625, 0.20%), etc.

Methods

The study was carried out in 2 phases. In the first phase, we selected 5 different fibers, including 2 coniferous pulps and 3 hardwood pulps and investigated the individual fiber characteristics as well as the degree of refining on the handsheet properties. In the second phase, we simulated the mill-site formulations and separately blended the 2 softwood (350 mL CSF) and the 3 hardwood fibers (250 mL CSF) for a total of 6 combinations and examined the effects of blending on handsheet properties. The fiber characteristics examined included pulp freeness (TAPPI T227 om-99, Liensheng Co., Taiwan), fiber length, coarseness, and fiber population (TAPPI T234 cm-84, Kajaani FS 200); the handsheet properties examined included grammage (TAPPI T410 om-96), thickness (TAPPI T411 om-97), bulk, dry opacity (TAPPI T425 om-96, Color-Eye 3000, Macbath), wet opacity (Color-Eye 3000, Macbath), air resistance (TAPPI T460 om-96, Gurley method, Liensheng Co.), and water absorption (TAPPI T441 om-98, Cobb sizer, Toyoseike, Japan).

Pulp refining in the experiment simulated typical paper mill on-site stock blending principles and used a laboratory Valley beater (Liensheng Co.) to refine the pulp specimens. Softwood pulps were beaten from their original freeness to 550 and 350 mL CSF; while hardwood pulps were beaten from their original freeness to 450 and 250 mL CSF, respectively.

Handsheets preparation was carried out in accordance with the TAPPI T205 sp-95 method. The experimental procedure entailed the following: Pulps were individually disintegrated using a standard disintegrator. The pH was adjusted to 7.5 with Na_2CO_3 while the mixture was stirred. Kymene 557 at 0.4% to dry pulp was added and stirred for 60 s. Then it was followed sequentially by Nalco 7607 at 0.35% to dry pulp, Hercon 76 at 0.30% to dry pulp, and Nalco 625 at 0.20% to dry pulp each was added and stirred for 60 s. Upon completion of the chemical addition, handsheets of 60 gsm grammage were formed using a standard sheet mold. The handsheets were air-dried overnight and conditioned in a constant temperature and humidity room for at least 3 h before testing the handsheet properties.

RESULTS AND DISCUSSION

Fiber morphological characteristics

The main functions of refining are to fibrillate, crush/collapse, and cut pulp fibers so as to make them conform to the property requirements of the final products. Table 1 shows the freeness and fiber morphological indicators of the 5 wood pulps before and after refining. The softwood pulps had longer fibers than the hardwood pulps (northern softwoods > radiata pine > Indonesian hardwoods > eucalyptus > acacia); whereas fiber coarseness showed a similar trend with radiata pine > northern softwoods > Indonesian hardwoods > eucalyptus > acacia. Fiber populations, on the other hand, showed a reverse trend of acacia > eucalyptus > Indonesian hardwoods > northern softwoods > radiata pine.

An increase in the pulp refining degrees entailed an increase in the ratio of fines. The fiber lengths exhibited an inverse relationship with the degree of refining; the fiber population values showed a positive correlation with the degree of refining. The coarseness values, on the other hand, exhibited irregular patterns depending on the degrees of fracturing of the S_1 and S_2 layers of the cell walls.

Table 2 shows the fiber morphological indicators when each of the softwood (350 mL CSF) and hardwood pulps (250 mL CSF) was blended at various ratios for a total of 6 sets. Along with an increase in the blending ratios of hardwood pulps, the freeness, fiber length and coarseness of the pulp furnishes tended to decrease while the fiber population tended to increase. The furnish sets containing radiata pine pulp had fiber lengths slightly lower than those of the northern softwoods pulp furnishes. The 2 groups did have similar fiber coarseness and populations. The results also indicated that by using refining and adjusting the blend ratios of softwood and hardwood pulps, the desired paper machine stock freeness and fiber morphological characteristics could be achieved.

Effects of the individual fiber characteristics and degrees of refining on handsheet properties

The laboratory pulp refining was based

Table 1. Effects of refining on the fiber morphological characteristics

Symbol	Pulp type	Freeness (mL, CSF)	Fiber length (mm)	Coarseness (mg m^{-1})	Population (10^6 fibers g^{-1})
N-700	Northern softwoods BKP	713	2.44	0.202	2.01
N-550		552	2.09	0.186	3.05
N-350		344	1.90	0.185	3.13
R-700	Radiata pine BKP	705	2.34	0.251	1.64
R-550		544	1.99	0.246	2.52
R-350		342	1.75	0.241	2.97
E-600	Eucalyptus BKP	612	0.75	0.084	10.20
E-450		448	0.63	0.088	12.60
E-250		246	0.61	0.095	12.80
I-600	Indonesian hardwoods BKP	621	0.66	0.077	13.30
I-450		442	0.53	0.080	18.20
I-250		270	0.40	0.079	25.70
A-700	Acacia BKP	598	0.93	0.129	7.09
A-450		464	0.72	0.128	10.30
A-250		265	0.58	0.118	13.20

N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

Table 2. Effects of blending pulp furnishes of softwood and hardwood fibers on the fiber morphological characteristics

Symbol	Furnishes	Freeness (mL, CSF)	Fiber length (mm)	Coarseness (mg m^{-1})	Population (10^6 fibers g^{-1})
N/E	100/0	344	1.90	0.185	3.13
	75/25	317	1.58	0.163	5.55
	50/50	290	1.26	0.140	7.97
	25/75	254	0.93	0.118	10.38
	0/100	246	0.61	0.095	12.80
N/I	100/0	344	1.90	0.185	3.13
	75/25	338	1.57	0.168	5.65
	50/50	308	1.24	0.152	8.17
	25/75	278	0.91	0.135	10.68
	0/100	265	0.58	0.118	13.20
N/A	100/0	344	1.90	0.185	3.13
	75/25	337	1.53	0.159	8.77
	50/50	309	1.15	0.132	14.42
	25/75	276	0.78	0.106	20.06
	0/100	270	0.40	0.079	25.70
R/E	100/0	342	1.75	0.241	2.97
	75/25	316	1.47	0.205	5.43
	50/50	296	1.18	0.168	7.89
	25/75	264	0.90	0.132	10.34
	0/100	246	0.61	0.095	12.80
R/I	100/0	342	1.75	0.241	2.97
	75/25	331	1.46	0.210	5.53
	50/50	302	1.17	0.180	8.09
	25/75	277	0.87	0.149	10.64
	0/100	265	0.58	0.118	13.20
R/A	100/0	342	1.75	0.241	2.97
	75/25	324	1.41	0.201	8.65
	50/50	298	1.08	0.160	14.34
	25/75	275	1.61	0.120	20.02
	0/100	270	0.40	0.079	25.70

N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

on simulation of on-site refining principles. A laboratory Valley beater was used to refine the softwood pulp from the original freeness to 550 and 350 mL CSF, and the hardwood pulp from the original freeness to 450 and 250 mL CSF.

Bulk

Figure 1 shows the effects of pulp type and degrees of refining (freeness) on the bulk of the handsheets. The figure shows that bulk decreased with an increasing degree of refining. Under identical pulp freeness values, hardwood pulps produced papers with higher bulks than those of the softwood pulps. The ranking in decreasing order of bulkiness was Indonesian hardwood, acacia, eucalyptus, ra-

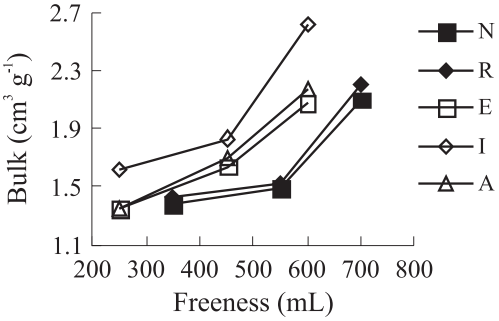

Fig. 1. Effects of pulp and freeness on the handsheet bulk. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

diata pine, and northern softwood pulps.

The higher the coarseness of the softwood pulp, the greater the paper bulk of the resulting paper was; the same held true for the hardwood pulps, with the exception of eucalyptus pulp. For the mixed Indonesian hardwood pulp in particular, with an average cell wall thickness of 7.3 μm, it had the highest coarseness and produced the bulkiest paper as a consequence (Hillman 1998).

Water absorption

Figure 2 shows the effects of pulp type and degree of refining (freeness) on the water absorption of the handsheets. Water absorption is represented by the Cobb value. The lower the Cobb value, the more water resistant the paper was. The figure shows that water absorption increased with an increasing degree of refining. Under a similar freeness, hardwood fibers had lower water absorption levels than softwood fibers. The overall ranking in decreasing order was radiata pine, northern softwoods, acacia ≈ eucalyptus, and Indonesian hardwoods.

Comparing the results of water absorption to those of coarseness values in Table 1, the relationship was irregular, indicating that water absorption was related to the tree species, and radiata pine had the highest water absorption.

Air permeability

The effects of pulp type and degree of refining on the air permeability of the handsheets are shown in Fig. 3. A higher number of seconds in the air permeability values means the paper surface is smoother and more resistant to air penetration. Based on the results of Fig. 3 and Table 1, it is clear that the higher the degree of refining, the lower the pulp freeness and coarseness, and the higher the fiber populations became, rendering the handsheets tighter-textured and more

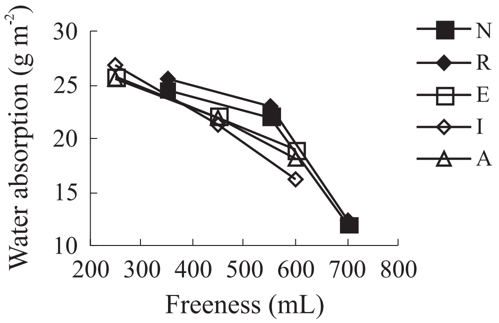

Fig. 2. Effects of pulps and freeness on the handsheet water absorption. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwood; A, acacia.

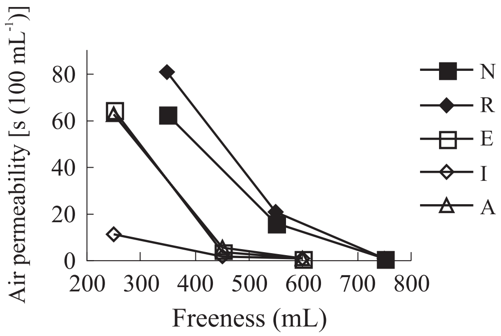

Fig. 3. Effects of pulp and freeness on the handsheet air permeability. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

resistant to air flow, i.e., less permeable to air. Under identical freeness values, softwood pulps (radiata pine > northern softwoods) had air permeability values greater than those of hardwood pulps (eucalyptus ≈ acacia > Indonesian hardwoods). The higher the coarseness of the softwood pulps, the greater the air permeability value of the resulting paper became; among the hardwood pulps, despite differences in fiber coarseness, eucalyptus and acacia produced papers of similar air permeability. The thick-walled Indonesian hardwood pulp had high coarseness and tended to form paper with high bulk and rough surfaces, and hence had the lowest air permeability value. The feature was not amenable to modification by refining.

Opacity

The effects of pulp type and degree of refining on the dry opacities of the handsheets are shown in Fig. 4. The figure shows that opacity decreased with an increasing degree of refining. Because all the hardwood pulps had higher intrinsic wood specific gravities, they hence had relatively thicker fiber cell walls than those of softwood pulps, despite their lower fiber coarseness. This coupled with their greater numbers per unit area (population) caused the handsheets made from the same freeness hardwood fibers to have higher opacities (in the decreasing order of acacia, Indonesian hardwoods, and eucalyptus) than those made of softwood pulps (northern softwoods, and radiata pine).

The results showed that along with an increased degree of refining, the resulting paper had decreasing opacities. This is consistent with the knowledge that refining modifies the fiber morphology, causing the resulting sheets to have closer fiber-to-fiber bonds and a tighter structural geometry. The increase in optical contacts among the fibers means that opportunities for fiber-to-air light reflection and refraction are reduced, leading to a reduction in opacity.

Figure 5 illustrates the influence of pulp type and freeness on the wet opacity of the resulting handsheets. The wet opacity of handsheets showed a similar trend with their dry counterparts. Under an identical freeness, the wet opacity of hardwood handsheets was higher than values of softwood handsheets. The overall rank in decreasing order was acacia, Indonesian hardwood, eucalyptus, radiata pine, and northern softwoods pulps.

The wet opacities of the handsheets were often 2~6.5% ISO lower than the correspond-

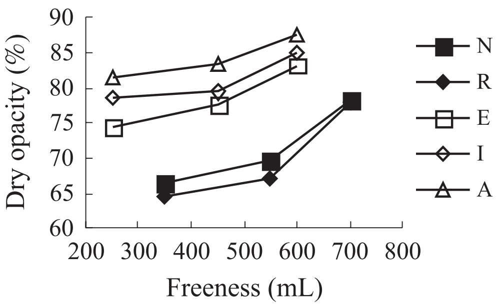

Fig. 4. Effects of pulp and freeness on the handsheet dry opacity. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

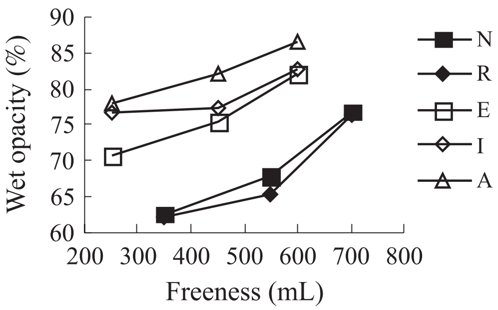

Fig. 5. Effects of pulp and freeness on the handsheet wet opacity. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

ing dry opacities. With an increased degree of refining, however, the differences expanded, suggesting that the handsheets formed from well-beaten pulps tended to generate large amounts of fines and absorb more water, which in turn caused the wet opacities to decrease.

Paper opacity is influenced by the light-scattering coefficient and the bulk of the handsheet. The fiber populations of hardwood pulps were far higher than those of softwood pulps; hence in general, they tended to have higher opacities at similar freeness values. The higher the population of the softwood pulp, the higher was the opacity of the resulting paper as well. Among hardwood pulps, acacia (25.7×10^6 fibers g^{-1}) had a higher fiber population than eucalyptus (12.8×10^6 fibers g^{-1}), hence a higher paper opacity. However, the Indonesian hardwoods had an average cell wall thickness (7.3 μm) much higher than those of acacia and eucalyptus (3.6 and 2.5 μm, respectively) (Hillman, 1998), and the highest paper bulk among the handsheets (Fig. 1). In this case, the influence of the bulk weight was elevated, and the effect of the light-scattering coefficient was diminished. Thus, when examining the factors affecting the opacity of Indonesian hardwood handsheets, the bulk must be considered. Although the fiber population of Indonesian hardwoods (13.2×106 fibers g^{-1}) was lower than that of acacia and comparable to that of eucalyptus, its handsheet opacity was higher than that of eucalyptus and lower than that of acacia. Yet at a freeness of 250 mL CSF, its handsheet had a wet opacity comparable to that of acacia. This evidence provides support for the observed trend that the pulp fiber population had a positive correlation with the resulting paper opacity at similar handsheet bulk conditions.

Effects of fiber characteristics and the degree of refining of blended furnishes on the properties of handsheets

Laboratory refining and furnish blending were based on simulating mill-site practices in principle. Blends were made by mixing the 2 softwood pulps at 350 mL CSF and the 3 hardwood pulps at 250 mL CSF individually at different ratios to give a total of 6 sets.

Bulk

The effect of furnishes on the handsheet bulk is shown in Fig. 6. When softwood pulps were individually blended with hardwood pulps, the furnishes generally provided no improvement in the paper bulk, except for those containing Indonesian hardwood pulp as shown in Fig. 6. Thick-walled Indonesian hardwoods pulp in combination with radiata pine generated the least paper density (highest bulk); the northern softwood-acacia furnish, on the other hand, had the lowest bulk. The rank in paper bulk of the blended furnishes was radiata pine-Indonesian hardwoods, northern softwood-Indonesian hardwoods, radiata pine-eucalyp- tus, northern softwood-eucalyptus, radiata pine-acacia, and northern softwood-acacia. The experimental results strongly indicated that fiber cell wall thickness influenced the compression properties

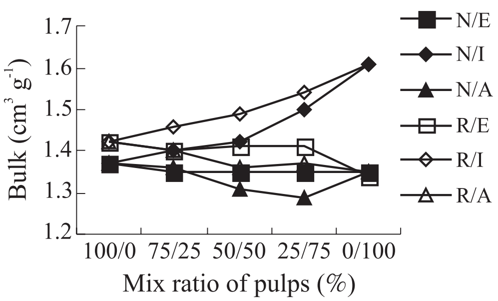

Fig. 6. Effects of furnishes on the handsheet bulk. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

and conformability of the paper sheets, and hence impacted the bulk of the resulting paper, and that bulk was inversely correlated to the air permeability value.

Effects of fiber coarseness on the bulk of the papers are shown in Figure 7. Except for the Indonesian hardwoods group, blended furnishes (not counting the individual pulp groups) gave paper bulk positively correlated to their coarseness. As for the Indonesian hardwoods pulp containing groups, the extra-high bulk of the pulp resulted in furnishes blending softwood pulps to produce paper having bulk positively correlated to Indonesian hardwoods pulp content and negatively correlated to the coarseness value.

Water absorption

The effects of furnishes on the water absorption of handsheets are shown in Fig. 7. Water absorption is represented by the Cobb value. The figure shows that blending hardwood and softwood pulps could reduce the water absorption, or in other words, increase the water resistance of the resulting handsheets. The degree of water absorption reduction tended to increase with an increasing proportion of the hardwood pulp. When northern pine was blended with acacia, the lowest water absorption value was observed. And a blend of radiata pine and eucalyptus pulps produced handsheets with the highest water absorption of the blended furnishes. The ranking in decreasing order of the water absorption of the blended furnishes was radiata pine-eucalyptus, radiata pine-Indonesian hardwoods, northern softwood- eucalyptus, radiata pine-acacia, northern softwood-Indonesian hardwoods, and northern softwood-acacia.

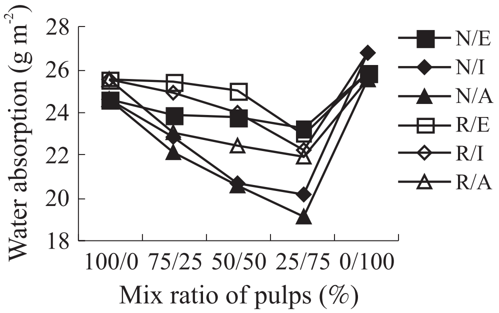

Fig. 7. Effects of furnishes on the handsheet water absorption. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

As shown in Fig. 7, blending softwood and hardwood pulps produced papers with increased water resistance. Often the more hardwood pulp that was included, the better the water resistance of the resulting handsheets was. Thus a 25:75 ratio of softwoods: hardwoods produced a high water resistance. Pure (100%) hardwood furnishes had the highest water absorptions; and pure softwood pulps had lower water absorptions than hardwood pulps. This was due to the lower hardwood freeness which entailed greater proportions of fines in the pulp and which in turn caused insufficient reactions with the fixed AKD dosage or was less able to retain the chemical. At the ratio of 25:75, the fines of the furnish produced a balance with the tighter paper texture which enhanced the overall water resistance of the paper.

Air permeability

The effect of furnishes on the air permeability of handsheets is shown in Fig. 8. The longer it takes to allow 100 mL of air to escape from the paper surface or pass through the paper layer means that the paper is smoother and less permeable to air flow (i.e., with a higher air resistance). The figure shows that with an increased acacia pulp proportion in the furnish, the air permeability value increased. However, when acacia made up > 50% of furnishes, the air permeability value

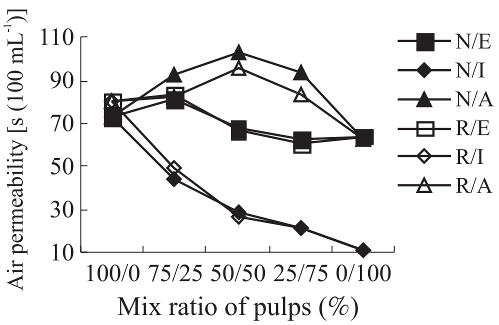

Fig. 8. Effects of fiber coarseness on the handsheet air permeability. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

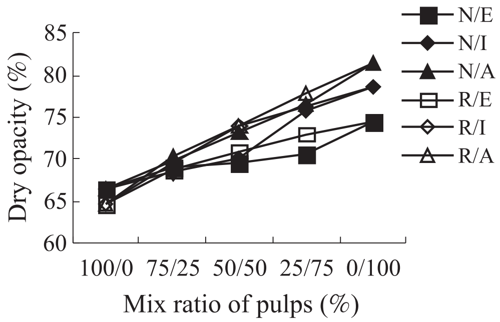

Fig. 9. Effects of furnishes on the handsheet dry opacity. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

decreased somewhat. A northern softwood/acacia pulp ratio of 50:50 led to the highest air permeability value of 102 s (100 mL)$^{-1}$, suggesting a tightly textured and smooth-surfaced paper. Blending softwood with eucalyptus or Indonesian hardwood, however, provided no air resistance advantage. Often the air permeability value decreased with increasing proportion of these pulps, particularly with the Indonesian hardwood pulp. This was probably due to its higher coarseness and lower population feature. The rank of air permeability values of the blended furnishes was northern softwood-acacia, radiata pine-acacia, northern softwood-eucalyptus ≈ radiata pine-eucalyptus, radiata pine-Indonesian hardwoods ≈ northern softwood-Indonesian hardwoods.

Opacities

The effect of furnishes on the dry opacity of handsheets is shown in Fig. 9. The higher the proportion of softwood pulp, the lower was the opacity in general. When softwood pulps were separately blended with acacia pulp, the handsheets had the highest opacities. Blending with Indonesian hardwood pulp resulted in papers with intermediate opacities, while blending with eucalyptus pulp gave paper the lowest opacities. Although northern softwood pulp at 350 mL CSF produced handsheets with a higher opacity than the radiata pine pulp at the same freeness, once blended with hardwood pulps, however, the furnishes containing radiata pine produced handsheets with higher opacities than those containing the northern softwood pulp.

The effect of furnishes on the wet opacity of handsheets is shown in Fig. 10. The trends in handsheet wet opacity for the blended furnishes were similar to those of the dry opacity. The higher the proportion of the softwood pulp, the lower the wet opacity of the handsheet became. Among the furnishes, softwood pulps blended with acacia pulp produced handsheets with the highest wet opacities. Following closely behind were furnishes containing softwood pulps and Indonesian hardwood pulp. Lagging behind in wet opacity were furnishes of softwood and eucalyptus pulp. This was probably because eucalyptus pulp tended to absorb more water than Indonesian hardwood and acacia pulps. The difference in dry opacities between the northern softwood and radiata pine groups was diminished in their respective wet opacities probably because radiata pine was more water absorbent (Figs. 2, 7).

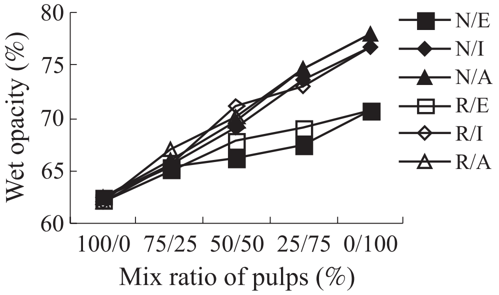

Fig. 10. Effects of furnishes on the handsheet wet opacity. N, northern softwood; R, radiata pine; E, eucalyptus; I, Indonesian hardwoods; A, acacia.

Regardless of the dry or wet experimental sets, paper opacity exhibited a linear correlation with the furnish blend ratio, hence the opacity of a blended paper could be estimated from the opacities of the individual softwood and hardwood fibers.

CONCLUSIONS

Among individual fiber morphological indicators, the decreasing rank of fiber lengths was northern softwoods, radiata pine, Indonesian hardwoods, eucalyptus, and acacia; that for fiber coarseness was radiata pine, northern softwoods, Indonesian hardwoods, eucalyptus, and acaica; and for fiber population, it was acacia, eucalyptus, Indonesian hardwoods, northern softwoods, and radiata pine. With an increase in pulp refining, the values of fiber populations showed a positive correlation with the degree of refining, whereas pulp freeness and fiber length were negatively correlated. Coarseness showed irregular trends with the degree of refining.

The blended furnish study indicated that increased proportions of hardwood pulp, pulp freeness, fiber length and coarseness were all negatively correlated; while fiber populations were positively correlated. By using the degree of pulp refining and blending of long- and short-fiber pulps a stock with suitable freeness and fiber morphological characteristics can be obtained for paper machine operation.

Handsheets prepared from individual pulps indicated that paper bulk and opacities (both dry and wet) decreased with an increasing degree of refining and exhibited negative correlations. Water absorption and air permeability of the papers, on the other hand, increased with an increasing degree of refining and had positive correlations. Hardwood pulps had higher paper bulk and opacities than those of softwood pulps; while softwood pulps had higher water absorption and air permeability values than those of hardwood pulps. The fiber morphological properties, coarseness, and population effects on the paper bulk, water absorption, air permeability, dry and wet opacities were pulp specific and varied in irregular patterns.

The blended furnish study results suggested that along with an increasing proportion of hardwood pulp, the paper bulk of the Indonesian hardwoods group showed a positive correlation, while those of eucalyptus and acacia exhibited an inverse relationship. Water absorption and air permeability were negatively correlated with the hardwood proportion; the opacities were positively correlated. Fiber coarseness was positively correlated to paper bulk and water absorption (except for the Indonesian hardwoods). The relationships of the paper air permeability with fiber coarseness and populations were furnish-dependent, while paper opacities appeared to be positively correlated with fiber populations except for the Indonesian hardwoods.

Paper opacity exhibited a linear correlation with the furnish blend ratio; therefore, the opacity of a blended paper can be estimated from the opacities of the individual softwood and hardwood fibers.

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