FINES OF *ACACIA MANGIUM* RECYCLED KRAFT PAPER

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RUSHDAN, I. 2005. Fines of *Acacia mangium* recycled kraft paper. The effects of initial refining degree (32, 56 and 70° SR) on the quantity and quality of fines of *Acacia mangium* unbleached kraft recycled papers were studied. The retention of fines and the effect of these fines on the bonding index of handsheets were also studied. The fines' content and retention were determined using the Dynamic Drainage Jar. The fines size and zeta potential were analysed by the COULTER® DELSA 440. Fines were reduced from pulp stocks at different levels by Dynamic Drainage Jar and these stocks were then converted into handsheets. The fines were found to vary in quantity (3.0 to 8.5%) and quality (average size of 1.5 to 2.2 μm and average zeta potential of -30.6 to -44.3 mV) for different initial refining degrees. The amounts at which the recycled fines were retained in the stock also varied (91.4 to 48.3%) for different recycled pulps and this depended on the initial refining degree and the drainage shear. The bonding index of recycled papers was found to decrease with reduction in fines content (25 to 34%).

Key words: Drainage shear – refining – retention – unbleached kraft pulp – zeta potential

RUSHDAN, I. 2005. Halusan dalam kertas kraf *Acacia mangium* yang dikitar semula. Kesan darjah penghalusan awal (32°, 56° and 70° SR) ke atas kuantiti dan kualiti halusan kertas kitar semula pulpa kraf tak luntur *Acacia mangium* dikaji. Pengekalan halusan di dalam stok dan kesan halusan ke atas indeks ikatan kertas makmal juga dikaji. Kuantiti dan pengekalan halusan dalam stok pulpa ditentukan menggunakan *Dynamic Drainage Jar*. Saiz halusan dan keupayaan zeta halusan diukur menggunakan COULTER® DELSA 440. Kuantiti halusan di dalam stok-stok pulpa dikurangkan pada darjah berlainan menggunakan *Dynamic Drainage Jar* dan stok ini kemudiannya dijadikan kertas makmal. Halusan-halusan ini berbeza dari segi kuantiti (3.0% hingga 8.5%) dan kualiti (purata saiznya 1.5 μm hingga 2.2 μm dan purata potensi zetanya -3.6 mV hingga -44.3 mV) untuk darjah penghalusan awal yang berbeza. Kuantiti halusan kitar semula yang kekal di dalam stok juga berbeza (91.4% hingga 48.3%) untuk pulpa kitar semula yang berlainan. Ini bergantung kepada darjah penghalusan awal dan nilai ricih saliran. Nilai indeks ikatan kertas kitar semula didapati berkurangan apabila kandungan halusan berkurangan (25% hingga 34%).

Introduction

Besides fibres, there are fines in pulp. Fines play a vital role in productivity and in the overall economics of paper manufacturing. Fines are defined as any particles that pass through a 75 μm hole (200 mesh) (Htun & de Ruvo 1978, Kershaw 1980, Sunberg *et al.* 2003) but excluding any soluble or colloidal materials (Scott 1986).

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Chemical composition of fines is similar to the fibre but their crystallinity is lower (Waterhouse & Omori 1993).

The fines are formed partly as the fibres separate from each other and partly as the surface of fibres peels during refining (Heikkurinen 1999). The characteristics of fines depend on the mechanical process, which the pulp has undergone. Kibblewhite (1975) found out that different beating processes created different quantity and quality of fines. The amount of fines increases approximately linearly with refining (Sandgren & Wahren 1960, Kibblewhite 1975), and the rate and level of fines generation is dependent on species and pulp type (Mancebo & Krokoska 1985). The thick-wall fibres form more fines than the thin-wall fibres (Paavilainen 1991). Refining at higher consistency could reduce the rate at which fines are formed. Paavilainen (1990) also reported that refining of earlywood and latewood produced a different amount and quality of fines.

All wood pulp fibres and fines contain electrically charged groups that can be carboxyl, sulphonate or phenolate depending upon the pH, wood species and the pulping process (Eklund & Lindström 1991). Fines are surrounded by a dense layer of ions having a specific electrical charge. This layer is surrounded by another layer, which has an electrical charge of its own. The bulk of the suspended liquid also has its own electrical charge. The difference in electrical charge between the dense layer of ions surrounding the particle and the bulk of the suspended liquid is known as zeta potential. The greater the zeta potential, the more the fines will repel each other. Conversely, a low zeta potential is likely to result in fines clumping (Smook 1992).

The fines, which are not retained in the sheet, are lost with the white water overflow from the system. Fines substantially increase the volume of effluent. In a closed system, recycling white water, the unretained fines will accumulate in the headbox; subsequently retard drainage and the fines absorb a disproportionate amount of certain additives by virtue of its high specific surface (Smook 1992, Li *et al.* 2002). It is established that retention is a key factor in the wet-end, giving an indication of the stability of the whole papermaking process. Variations in retention cause paper quality to fluctuate.

The presence of fines has both negative and positive effects on paper properties depending on their chemical composition. For chemical pulps, the removal of fines caused a reduction in tensile strength, folding endurance burst and stiffness but an increase in the tear factor and zero-span (Thode & Ingmanson 1959, Tasman 1966, Htun & de Ruvo 1978, Klungness & Sanyer 1981). Higgins and Hartman (1983) found the addition of 15% fines produced an increase in tensile strength properties in the sheet. Retulainen *et al.* (1993) reported that fines addition gave remarkable improvements to tensile strength, light scattering coefficient and smoothness of paper.

During recycling, fines are also hornified as fibre (Szwarcsztajn & Przybysz 1976, de Ruvo & Htun 1981, Mancebo & Krokoska 1985). Unlike fibres, fines hornification was irreversible, and therefore considered as a filler material. When fines act as a filler material, it has a negative impact on strength (Mancebo & Krokoska 1985). However, Hawes and Doshi (1986) found that recycled fines increased the paper strength. The effects of the quality and quantity of recycled fibre fines on stock retention and sheet are not perfectly understood (Retulainen *et al.* 1993, Waterhouse & Omori 1993). The objective of this study was to investigate the characteristics of recycled pulp fines of *Acacia mangium* kraft paper: quantity, size, zeta potential, retention and paper bonding index.

Materials and methods

Initial refining

In this study, an unbleached kraft pulp (Kappa number 20) was used. The pulp was produced from a thinning residual of *A. mangium* collected from a Compensatory Forest Plantation in Kemasul, Pahang. The virgin pulps were refined in a disk refiner at three different levels of energy input: 25, 100 and 150 kWh t^{-1} and their wetness were 32, 56 and 70° SR. These pulps were converted into papers and recycled. These recycled papers were labelled as Acacia32, Acacia56 and Acacia70 that corresponded to their initial wetness. The papers were soaked overnight and repulped and converted into paper according to TAPPI T205 om-88 'Forming handsheets for physical tests of pulp' (TAPPI 1994).

Fines content, size and zeta potential

The fines content and fines separation from fibre were determined using the Dynamic Drainage Jar as stipulated in TAPPI T 261 cm-90, 'Fines Fraction of Paper Stock by Wet Screening' (TAPPI 1994). This experiment was repeated three times.

Particle size was measured using the COULTER DELSA 440. The instrument is sensitive over a wide range of particle sizes, ranging from 10 nm to 30 µm (Sanders & Schaefer 1989). Ten measurements were made on each stock. Fines shape was not determined in this work since the instrument for this purpose was not available.

Zeta potential was measured by electrophoretic mass transport using the COULTER DELSA 440. The analysis was menu driven. Ten measurements were made on each stock.

Fines retention

The retention of fines was also studied using the Dynamic Drainage Jar as stipulated in TAPPI T 261 cm-90 (TAPPI 1994). The degree of retention over a range of turbulence indicates the performance effectiveness or flocculation index of fines in a specific stock (Britt & Unbehen 1976). The system was characterized by determining the retention over a range of stirrer speeds used (0, 250, 500, 750 and 1000 rpm). This experiment was repeated three times.

Effect of retention of fines on bonding index

The presence of fines has an effect on paper bonding index. Papers containing different levels of fines were made. Fines were reduced from the pulp stocks at different levels as stipulated in TAPPI T 261 cm-90 (TAPPI 1994) and these stocks were then converted into handsheets. All handsheets were prepared and tested according to TAPPI T 205 om-88 (TAPPI 1994) and TAPPI T 220 om-88 'Physical testing of pulp handsheets' (TAPPI 1994). The bonding index of recycled papers was calculated using Page's simplified equation (Page 1969, Cilder & Howarth 1972, Moss 1989, Gorres *et al.* 1995).

Results and discussion

Fines content, size and zeta potential

The fines diameter for Acacia32, Acacia56 and Acacia70 were in the range of 1.2 to 2.2, 1.1 to 1.8 and 1.6 to 2.6 µm respectively. The zeta potential for Acacia32, Acacia56 and Acacia70 were in the range of -36.9 to -48.0, -17.5 to -43.0 and -39.3 to -47.2 mV respectively. The distribution of diameter and zeta potential of fines were not available because the instrument could only take average readings of each sample. The differences in quantity and quality of fines were due to the processes they had undergone (Htun & de Ruvo 1978, Kershaw 1980, Mancebo & Krokoska 1985).

Recycled paper Acacia70 had the most fines (Table 1). The higher degree of initial refining during papermaking had increased the quantity of fines in recycled pulp. The fines production was caused by fibre shortening due to fibre structural weakness and inflexibility, and removal of the fibre wall during the initial refining.

Table 1 Fines characteristics of *Acacia mangium* unbleached kraft recycled pulps

Recyled pulp	Fines content (%)	Fines size (µm)	Zeta potential (mV)
Acacia32	3.01	1.72	-44.27
	(0.41)	(0.40)	(3.18)
Acacia56	3.81	1.49	-30.63
	(0.23)	(0.24)	(8.30)
Acacia70	8.47	2.21	-43.19
	(0.69)	(0.49)	(2.33)

Values in parentheses are standard deviations.

The increase in refining degree from 32° SR (Acacia32) to 70° SR (Acacia70) caused the fines to increase by 181.4%. Rushdan (2003) reported that the increase in refining degree had increased the fines content of soda pulp derived from oil palm empty fruit bunches. The increase in energy input of refining will increase fibre shortening and fibre wall removal (Sandgren & Wahren 1960, Kibblewhite 1975).

Acacia70 had the biggest average fines size, whereas Acacia56 had the smallest. The differences in fines diameter are due to the condition of original fibre —degree of fibre nodal dislocation and flexibility, and refining—degree of mechanical action (Kibblewhite 1972, Moss 1989).

The *A. mangium* recycled fines are negatively charged due to the presence of carboxyl groups in the cellulosic materials (Lindström *et al.* 1974). Wistara *et al.* (1999) found that recycling tend to increase the acid component of pulps. Acacia32 gave the highest zeta potential while Acacia56, the lowest. The zeta potential varied by 30.8%. The differences in zeta potential are due to the difference in surface charge, carboxylic groups in the cellulose and hemicellulose components of the pulp, and sulphonate groups in lignin (Eklund & Lindström 1991). Refining affects fibres in many ways including redistribution of hemicelluloses from the interior of the fibre to the exterior and dissolving or leaching out of colloidal material into the external liquor (Wistara *et al.* 1999, Lumiainen 2000). Sjostrom and Haglund (1963) found that during refining, 0.3 to 0.6% of pulp carbohydrates were dissolved. The different degrees of initial refining may affect the cellulose and hemicellulose of *A. mangium* pulps. Subsequently, the fines produced has different zeta potentials.

Fines retention

It is established that retention is a key factor in the wet-end, giving an indication of the stability of the whole papermaking process. In this work, the retention of fines in papermaking process was simulated. The fines retained in the stock varied according to the initial refining and agitation. The amount of fines retained decreased as agitation increased (Table 2). The percentage of fines retention of Acacia56 was highest whereas Acacia70 was lowest (Figure 1). Agitation strongly influenced the fines retention. The coefficient of determination (r^2) for Acacia32, Acacia56 and Acacia70 were 0.89, 0.95 and 0.77 respectively. The fines retention is affected by colloidal and shear forces (Britt & Unbehend 1976, Kershaw 1980). Colloidal forces, designated as zeta potential, are the forces of attraction between surfaces of fines and fibres. The greater the zeta potential, the more the fines will repel each other and less fines clumping (Smook 1992). The fines size and zeta potential might affect fines retention. Acacia 70 had the biggest size but lowest fines retention (Figure 1).

Table 2 Effect of agitation on the retention of *Acacia mangium* unbleached kraft recycled pulps

Agitation (rpm)	Fines retention (%)		
	Acacia32	Acacia56	Acacia70
0	83.61	84.30	91.41
	(3.45)	(9.15)	(11.84)
250	80.86	77.86	77.68
	(3.70)	(4.31)	(1.89)
500	64.84	75.64	71.14
	(4.69)	(3.79)	(10.27)
750	59.74	75.44	52.25
	(3.23)	(7.51)	(1.90)
1000	59.21	71.11	48.25
	(2.05)	(11.21)	(8.18)

Values in parentheses are standard deviations.

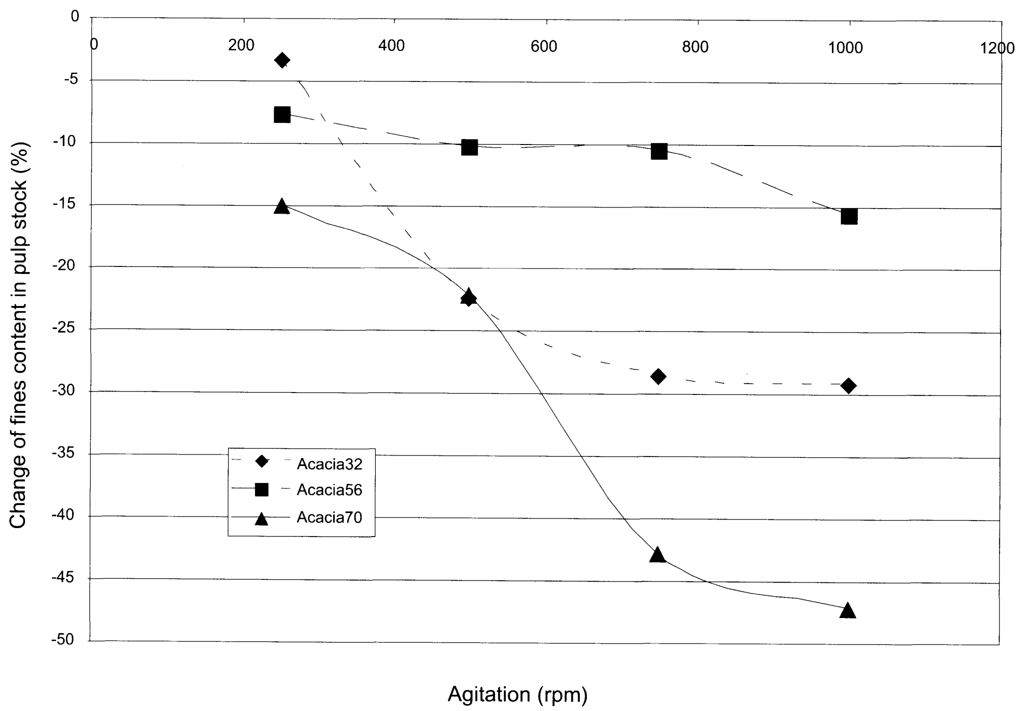

Figure 1 The effect of agitation on the retention of *Acacia mangium* recycled fines

Effect of fines on bonding index

Fines content (0 to 8.2%) affected bonding index. The coefficient of determination (r^2) for Acacia32, Acacia56 and Acacia70 were 0.93, 0.72 and 0.90 respectively. The increase in recycled fines content in sheet increased the bonding index of recycled paper (Table 3). The differences in bonding index between the highest fines retained in the sheets and fines-free sheets for Acacia32, Acacia56 and Acacia70 were 25.3, 34.4 and 27.6% respectively. In this study, the recycled fines did not act as filler as found by other researchers (Szwarcsztajn & Przybysz 1976, de Ruvo & Htun 1981, Manchebo & Krokoska 1985). Rushdan (1998) found that the initial processing affected the properties of recycled paper. Initial higher drying temperature had decreased the swelling of recycled pulp but initial high refining had increased its swelling. The recycled fines are acting like virgin fines—removal of fines causes a reduction of bonding index (Thode & Ingmanson 1959, Tasman 1966, Htun & de Ruvo 1978, Klungness & Sanyer 1981). Recycled fines are also reported to increase the bonding index because they increase the relative bonded area and reduce stress concentration (Tasman 1992). Moss and Retulainen (1995) and Seth (2003) found that the fibre bonding was improved by

Table 3 The effect of fines content of *Acacia mangium* unbleached kraft recycled pulps on the bonding index of recycled paper

Recycled paper	Fines content (%)	Bonding index (N m g^{-1})
Acacia32	3.04	65.90
	1.97	60.33
	1.80	63.06
	0	49.25
Acacia56	3.54	107.43
	2.52	121.32
	1.71	98.42
	0	70.46
Acacia70	8.19	110.05
	6.18	123.11
	5.83	120.82
	0	79.67

the addition of fines. Many workers found that different species and pulps have different bonding potentials (Retulainen *et al.* 2002, Mayank 2004).

Conclusions

Fines quantity and quality were different between different *A. mangium* unbleached kraft recycled pulps. Recycled fines retained in the stock also differed between recycled pulps, according to initial refining and drainage shear. The reduction of fines content decreased the bonding index of recycled paper. During papermaking of *A. mangium,* fines retention should be optimised. Optimising the fines retention not only increased the bonding index but also decreased the volume of effluent and increased drainage during papermaking.

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References

BRITT, K. W. & UNBEHEN, J. E. 1976. New methods for monitoring retention. *Tappi* 59(2): 37–44.

CILDER, H. & HOWARTH, P. 1972. The effect of re-use on paper strength. *Paper Technology* 13(5): 333–335.

DE RUVO, A. & HTUN, M. 1981. Fundamental and practical aspects of papermaking with recycled fibres. Pp. 195–225 in *Transaction of 7th Fundamental Research Symposium—The Role of Fundamental Research in Papermaking.* Cambridge.

EKLUND, D. & LINDSTRÖM, T. 1991. *Paper Chemistry: An Introduction.* DT Paper Science Publications, Grankulla.

GORRES, J., AMIRI, R. WOOD, J. R. & KARNIS, A. 1995. The shear bond strength of mechanical pulp fibres. *Journal of Pulp and Paper Science* 22(5): J161–J164.

HAWES, J. M. & DOSHI, M. M. R. 1986. The contribution of different types of fines to the properties of handsheets made from recycled paper. Pp. 613–620 in 1986 *Pulping Conference.* TAPPI Press, Atlanta.

HEIKKURINEN, A. 1999. Single fiber properties. Pp. 18–37 in Levlin, J. & Soderbjelm (Ed.) *Pulp and Paper Testing.* Finish Paper Engineers' Association & TAPPI, Fapet Oy, Finland.

HIGGINS, B. G. & HARTMAN, R. R. 1983. *Refining for Property Development.* The Institute of Paper Chemistry, Appleton.

HTUN, M. & DE RUVO, A. 1978. The implication of the fines fraction for properties of bleached kraft sheet. *Svensk Papperstidn* 81(16): 507–510.

KERSHAW, T. N. 1980. Sheet formation and drying. Pp. 965–1127 in Casey, J. P. (Ed.) *Pulp and Paper: Chemistry and Chemical Technology.* Volume 2. Third edition. John Wiley and Sons, New York.

KIBBLEWHITE, R. P. 1972. Effect of beating on fiber morphology and fiber surface structure. *Appita* 26(3): 196.

KIBBLEWHITE, R. P. 1975. Interrelations between pulp refining treatments, fibre and fines quality and pulp freeness. *Paperi ja Puu* 57(8): 519–526.

KLUNGNESS, U. H. & SANYER, N. 1981. Hardwood pulp utilization: separation of nonfibrous oak components. *Tappi* 64(2): 109–113.

LI, H., NI, Y. & SAIN, M. 2002. Characterization of BCTMP fines and their effect on sizing. *Tappi* 1(7): 3–7.

LINDSTROM, T., SOREMARK, C., HEINEGARD, C. & MARTIN-LOF, S. 1974. The importance of electrokinetic properties of wood fiber for papermaking. *Tappi* 57(12): 94–103.

LUMIAINEN, J. J. 2000. Refining of chemical pulp. Pp. 86–122 in Paulapuro, H. (Ed.) *Papermaking Part 1, Stock Preparation and Wet End.* Finnish Paper Engineers' Association and TAPPI, Fapet Oy, Finland.

MANCEBO, R. & KROKOSKA, P. 1985. The concept, properties and papermaking role of fines. *Papir A Celluloza* 36(11): V71–V81.

MAYANK, G. 2004. Recycling potential of baggase & wheat straw pulps. *Tappi* 3(9): 25–31.

MOSS, P. A. 1989. A study of the frozen-hydrated structure of pulp. PhD thesis, University of Manchester, Manchester.

MOSS, P. A. & RETULAINEN, E. 1995. Effect of fines on fibre bonding. Pp. 97–101 in *Proceedings of International Paper Physics Conference.* TAPPI, Atlanta.

PAAVILAINEN, L. 1990. Importance of particle size, fibre length and fines for the characterization of softwood kraft pulp. *Paperi ja Puu* 72(5): 516–526.

PAAVILAINEN, L. 1991. Influence of morphological properties of softwood fibres on sulphate pulp fibres and paper properties. Pp. 383–395 in *1991 International Paper Physics Conference.* Book 2. TAPPI Press, Atlanta.

PAGE, D. H. 1969. The theory for tensile strength of paper. *Tappi* 52(4): 674–681.

RETULAINEN, E., MOSS, P. & NIEMINEN, K. 1993. Effect of fines on the properties of fibre networks. Pp. 727–769 in *Transactions of the 10th Fundamental Research Symposium—Products of Papermaking.* Oxford.

RETULAINEN, E., LUUKKO, K., FAGERHOLM, K., PERE, J., LAINE, J. & PAULAPURO, H. 2002. Papermaking quality of fines from different pulps—The effect of size, shape and chemical composition. *Appita* 55(6): 457–460.

RUSHDAN, I. 1998. The effect of initial processing on the bonding index of *Acacia mangium* recycled paper. Pp. 57–65 in Mohd Nor, M. Y. *et al.* (Eds.) *Proceedings of the International Pulp and Paper Conference.* Forest Research Institute Malaysia, Kepong.

RUSHDAN, I. 2003. Effect of refining on fibre morphology and drainage of soda pulp derived from oil palm empty fruit bunches. *Journal of Tropical Forest Products* 9(1&2): 26–34.

SANDERS, N. D. & SCHAEFER, J. H. 1989. Zeta potential distribution in pulp/PCC mixtures. Pp. 69–74 in *1989 Papermaker Conference.* TAPPI Press, Atlanta.

SANDGREN, B. & WAHREN, D. 1960. Studies of pulp crill—Part 3: Influence of crill on some properties of pulp and paper. *Svensk Papperstidn* 63(24): 879–883.

SCOTT, W. E. 1986. Fines management and control in wet-end chemistry. *Tappi* 69(11): 30–34.

SETH, R. S. 2003. The measurement and significance of fines. *Pulp & Paper Canada* 104(2): 41–44.

SJOSTROM, E. & HAGLUND, P. 1963. Dissolution of carbohydrates during beating of chemical pulps. *Svensk Papperstidning* 66(18): 718–720.

SMOOK, G. A. 1992. *Handbook for Pulp and Paper Technologies.* Second edition. Angus Widle Publication, Vancouver.

SUNBERG, A., PRANOVICH, A. V. & HOLMBOM, B. 2003. Chemical characterization of various types of mechanical pulp fines. *Journal of Pulp and Paper Science* 29(5): 173–178.

SZWARCSZTAJN, E. & PRZYBYSZ. 1976. Investigation on changes in the properties of recycled pulp fractions. *Cellulose Chemistry Technology* 10(6): 737.

TAPPI. 1994. *TAPPI Test Methods 1994–1995.* TAPPI Press, Atlanta.

TASMAN, J. E. 1966. The mechanical modification of papermaking fibres. *Pulp and Paper Magazine of Canada* 67(12): T553–569.

TASMAN, J. E. 1992. Pulp and paper testing. Pp. 1–47 in Kocurek, M. J. (Ed.) *Mill Control and Control System: Quality and Testing, Environmental, Corrosion, Electrical.* Vol 9. TAPPI/CPPA, Atlanta/Montreal.

THODE, E. F. & INGMANSON, W. L. 1959. Factors contributing to the strength of a sheet of Paper 1: external specific surface and swollen specific volume. *Tappi* 42(1): 74–83.

WATERHOUSE, J. F. & OMORI, K. 1993. The effect of recycling on the fines contribution to selected paper properties. Pp. 1261–1292 in *Transactions of the 10th Fundamental Research Symposium—Products of Papermaking.* Oxford.

WISTARA, N., ZHANG, X. & YONG, R. A. 1999. Properties and treatments of pulps from recycled paper. Part II. Surface properties and crystallinity of fibers and fines. *Cellulose* 6(4): 325-348.