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Effects of the Various Mixing Ratios of Recycled Pulp on the Physical and Optical Properties of Handsheets and their Curl due to Laser Printing

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ABSTRACT

The objectives of this study were to determine the physical and optical properties of handsheets and also to ascertain the behavioral phenomena of their curl due to laser printing. Handsheets were separately produced from beaten hardwood, softwood and recycled pulp and also from various mixing ratios of the beaten pulp. The recycled pulp was derived from white wood-free shavings (WWFSs) and washed-WWFSs pulp slurries. The results demonstrated that hardwood and softwood pulp mixed with washed-WWFSs recycled pulp could produce higher apparent density handsheets than those mixed with WWFSs recycled pulp, even though the increased amount of WWFSs and washed-WWFSs recycled pulp used for making handsheets decreased the apparent density and tensile strength of handsheets. Most of the various ratios of WWFSs recycled pulp mixed with hardwood and softwood pulp could give slightly higher brightness and opacity handsheets than most of those of washed-WWFSs recycled pulp mixed with the same hardwood and softwood pulp. With laser printing, handsheets printed on their bottom side were curlier than those printed on their top side. This is possibly because a greater amount of inorganic materials, which was demonstrated in terms of ash content, derived from fillers and coating pigments were retained in the top side of the handsheets. The increase in ash content of handsheets also decreased the amount of curl. In this study, it is especially noteworthy to demonstrate that without any inorganic materials retained in handsheets, both the handsheets printed on the top and the bottom side had the same amount of curl.

Key words: curl, laser printing, recycled pulp

INTRODUCTION

Generally, a copying paper, which is a kind of office and administration paper, possesses 70-90 g/m^2 of basic weight and is used in an office for photocopying and non-impact printing with a photocopier and with a laser printer (Tillman, 2006). Both the photocopier and the laser printer employ the same electro-photographic process for duplicating images onto the surface of the paper. One of the important steps of the process is fixing or fusing images created by toner particles onto the surface of the paper with a heat of up to 200°C with pressure provided by a fuser assembly.

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Because this could cause the phenomenon of a paper sheet curling due to its fused surface shrinkage, the dimensional stability is very important for copying paper (Anonymous, 2006; Tillman, 2006).

In Thailand, according to the Thai Paper Industries Association (Anonymous, 2004), the consumed amount of printing and writing paper, including that of office and administration paper, was 626,000 tones in the year of 2003 and the forecasted figure of the consumption grows up to 916,000 tones for the year of 2008. With environmental and economical concerns, therefore, many paper mills in Thailand very much look forward to utilizing some recovered paper, e.g., recovered newspapers, magazines and copying paper, for producing printing and writing paper including office and administration paper. Even though there is a lack of information about the physical and optical properties of copying paper produced with various ratios of recycled pulp derived from white wood-free shavings (WWFSs) as well as its curl behavior due to photocopying and laser printing operations, WWFSs are popularly as a source of recycled pulp for making office and administration paper, especially copying paper, which may contain up to 100% of recycled pulp (Tillman, 2006).

Therefore, the objectives of this study were to determine the physical and optical properties of handsheets produced from various ratios of the recycled pulp derived from WWFSs and also to ascertain the behavioral phenomena of their curl due to a laser printing operation.

MATERIALS AND METHODS

Pulp slurry preparation

Virgin commercial bleached kraft pulps produced from hardwoods and from softwoods and WWFSs from unprinted wood-free paper sheets were subjected to disintegration separately to produce hardwood and softwood pulp slurries and WWFSs recycled pulp slurry according to the Tappi T 205 standard. Part of the recycled pulp slurry was washed on a 150-mesh wire screen to produce washed-WWFSs recycled pulp by using a water jet for removing fines and inorganic materials derived from fillers and coating pigments. Following the Tappi T 200 standard, all of the prepared pulp slurries, i.e. hardwood and softwood virgin pulp slurries, and WWFSs and washed-WWFSs recycled pulp slurries, were separately beaten with a Valley beater (Laurentzen and Wettress, Sweden) to possess 380 ml of Canadian Standard Freeness (CSF) before producing handsheets to test for physical, printing and optical properties.

Physical property and printing tests

Following the SCAN-C 26:79 standard, each set of fifteen handsheets with 70 g/m^2 of basic weight was prepared from each of the beaten pulp slurries separately and were also produced from various mixing ratios such as hardwood pulp : WWFSs recycled pulp (3:1, 1:1, 1:3), hardwood pulp : washed-WWFSs recycled pulp (3:1, 1:1, 1:3), softwood pulp : WWFSs recycled pulp (3:1, 1:1, 1:3), softwood pulp : washed-WWFSs recycled pulp (3:1, 1:1, 1:3). All handsheets were cut into 15 × 15 cm squares and then conditioned with 50±2% relative humidity and 23±1°C. In this study, the 70 g/m^2 of basic weight, which corresponded to that of commercial copying paper sheets, was selected to produce the handsheets for the purpose of comparison.

Ten conditioned handsheets from each set of the handsheets were randomly subjected to laser printing (hp laser jet series 1000, Hewlet Packard, Thailand) by which a half of them were printed on the top side and the other were printed on the bottom side with a printing area of about 50%, in a chessboard pattern. The remainders were subjected to determining basic weight, thickness, tensile strength, and the amount of inorganic materials in terms of ash content following the Tappi T 220 and T 211 standard. **Figure 1** shows the chessboard printing pattern and determination of the curl of printed handsheets.

Optical property tests

Following the Tappi T 205 standard, each set of five handsheets was produced from the same beaten pulps separately and also produced from the same mixing ratios of the beaten pulps mentioned above. They were conditioned with 50±2% relative humidity and 23±1°C before determining their brightness and opacity with a reflectometer (Automatic Reflectometer Model-3, Kumagai Riki Kogyo, Co.,Ltd., Japan) according to the Tappi T 452 and T 425 standard. In this study, the determined brightness and opacity of the handsheets were used to represent those of the printed handsheets produced with the same beaten pulps and the same mixing ratios.

RESULTS AND DISCUSSION

Table 1 shows the properties of handsheets produced from various pulps and their curl due to laser printing. As can be seen, the ash content of handsheets, which corresponded to the amount of inorganic materials in handsheets, increased with the increased amount of WWFSs and washed-WWFSs recycled pulp used for making handsheets. This is because WWFSs and washed-WWFSs recycled pulp possessed a high ash content of about 10 % and 1.4 % and part of these ash contents can be retained in the handsheets. The high value of ash content undoubtedly stemmed from inorganic materials such as fillers and coating pigments added to the original paper sheets during prior manufacturing, because hardwoods and softwoods, which are the source materials of bleached kraft pulp for producing printing and writing paper, naturally

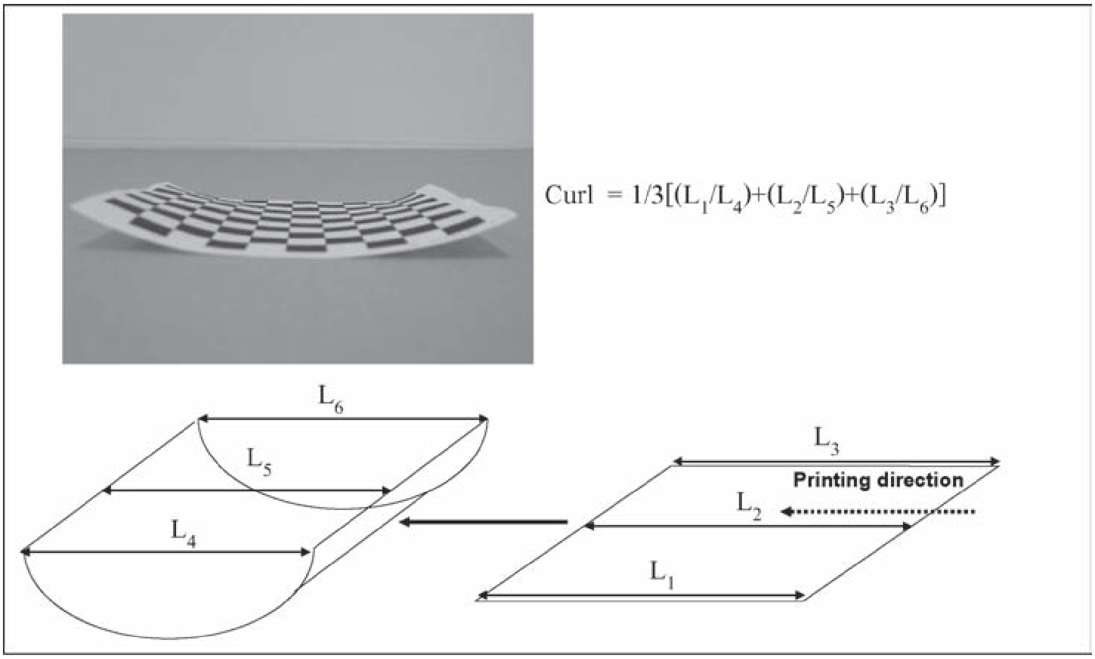

Figure 1 Chessboard printing pattern and determination of the curl of printed handsheet (15 × 15 cm).

inherit less than 1 % of ash content (Biermann, 1996). As also can be seen in **Table 1**, the ash content of hardwood and softwood pulp were 0.330 and 0.320 %, respectively. As a result, the increased amount of WWFSs and washed-WWFSs recycled pulps used for making handsheets decreased the apparent density and tensile strength of handsheets as demonstrated in **Figure 2(A)**. It could also be noted that both hardwood and softwood pulp mixed with washed-WWFSs recycled pulp could produce higher apparent density and tensile strength handsheets than those mixed with WWFSs recycled pulp mostly at the same mixing ratios. This is probably because higher apparent density was caused by a lack of good interfiber bonding areas mainly due to inferior swelling and conformability of hornified fibers derived from washed-WWFSs recycled pulp. A smaller effect of bonding interference due to a smaller amount of inorganic materials retained in the handsheets could be determined by the lowered values of ash content. Khantayanuwong *et al.* (2002) demonstrated that wet recycled fibers with poor swelling and conformability consequently could not provide good interfiber bonding contacts during wet sheet forming. **Figure 2(B)** demonstrates the effects of the various mixing ratios of WWFSs and washed-WWFSs recycled pulp, used for making handsheets, on the brightness and opacity of handsheets. Most of the

Table 1 Properties of handsheets produced from various ratios of pulps.

Handsheet samples	Properties						
	Apparent density (g/cm^3)	Brightness (%)	Opacity (%)	Tensile index (Nm/g)	Curl - Topside printed	Curl- Bottom side printed	Ash content (%)
H 100%	0.628±0.003	83.75±0.06	81.72±0.06	65.76±1.89	1.039±0.002	1.038±0.007	0.280±0.013
S 100%	0.624±0.009	82.93±0.47	80.03±0.01	66.41±2.15	1.035±0.002	1.034±0.005	0.220±0.003
W 100%	0.512±0.010	81.37±0.33	87.19±0.20	48.68±0.84	1.009±0.003	1.013±0.003	4.050±0.065
Ww 100%	0.531±0.005	83.27±0.40	84.89±0.78	59.46±1.35	1.049±0.007	1.049±0.005	0.830±1.022
H:W (3:1)	0.596±0.004	82.80±0.34	83.06±0.01	58.33±1.31	1.032±0.000	1.031±0.002	1.400±0.013
H:W (1:1)	0.572±0.004	84.33±0.51	82.37±0.08	53.42±0.89	1.032±0.003	1.031±0.002	2.120±0.036
H:W (1:3)	0.536±0.004	83.87±0.22	82.62±0.31	47.96±2.31	1.021±0.002	1.022±0.004	2.840±0.045
H:Ww (3:1)	0.599±0.003	82.48±0.25	82.23±0.16	60.97±1.60	1.042±0.000	1.042±0.005	0.490±0.002
H:Ww (1:1)	0.579±0.003	83.40±0.08	80.74±0.42	59.28±1.18	1.037±0.003	1.039±0.003	0.570±0.043
H:Ww (1:3)	0.563±0.005	82.48±0.71	81.05±0.02	58.99±2.34	1.035±0.004	1.038±0.002	0.730±0.031
S:W (3:1)	0.573±0.009	83.38±0.50	82.43±0.16	61.64±1.59	1.031±0.002	1.029±0.006	0.990±0.021
S:W (1:1)	0.567±0.006	84.05±0.17	81.48±0.04	55.63±1.88	1.026±0.006	1.024±0.000	2.000±0.063
S:W(1:3)	0.549±0.004	83.53±0.37	81.59±0.27	48.06±1.50	1.023±0.007	1.024±0.001	3.020±0.192
S:Ww (3:1)	0.595±0.008	83.35±0.30	80.19±0.29	64.50±2.51	1.039±0.006	1.041±0.002	0.310±0.012
S:Ww (1:1)	0.577±0.003	84.60±0.44	80.05±0.13	67.05±1.60	1.036±0.004	1.035±0.002	0.650±0.058
S:Ww (1:3)	0.547±0.005	82.50±0.31	80.41±0.18	64.30±1.31	1.034±0.003	1.039±0.003	0.490±0.019

N. B. 1. Each value is denoted at a range of 95 % confidence level.

2. H, hardwood pulp; S, softwood pulp; W, white wood-free shavings recycled pulp; Ww, washed white wood-free shavings recycled pulp.

3. Ash content in H, S, WWFSs, and washed-WWFSs were 0.330±0.010, 0.320±0.006, 9.610±0.441, and 1.430±0.016 %, respectively.

4. Curl in machine and cross-machine direction of commercial copy paper sheets printed on only top and on only bottom side were 1.023±0.005 and 1.028±0.014, and 1.020±0.008 and 1.029±0.002.

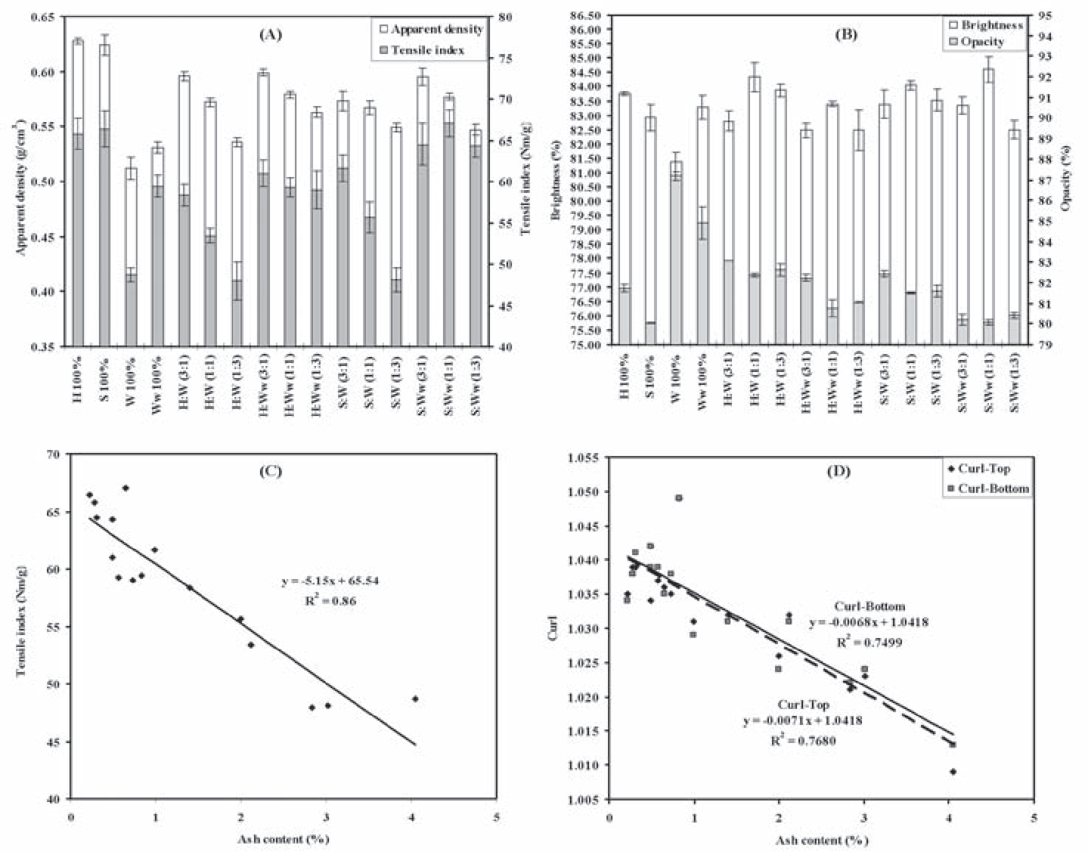

Figure 2 **(A)** and **(B)** Changes in the physical and optical properties of handsheets produced from various pulp ratios. **(C)** Relationship between the ash content and tensile strength of handsheets. **(D)** Relationship between the ash content and curl of the handsheets printed on only top and on only bottom side. N.B. H, hardwood pulp; S, softwood pulp; W, white wood-free shavings recycled pulp; Ww, washed white wood-free shavings recycled pulp. A pair of bars denotes a 95% confidence interval.

various ratios of WWFSs recycled pulp mixed with hardwood and softwood pulp could give slightly higher brightness and opacity handsheets than most of those of washed-WWFSs recycled pulp mixed with the same hardwood and softwood pulp, even though the brightness of washed-WWFSs recycled pulp itself was higher than that of WWFSs recycled pulp probably due to the lower amount of impurities in the washed-WWFSs recycled pulp. This is probably because the inorganic materials retained in handsheets, which were demonstrated in terms of their ash contents, caused some interfiber debonding areas which contributed to the light scattering of handsheets (Leskela, 1998). Ash content values demonstrated in **Table 1** and the relationship between the ash content and the tensile strength of handsheeets demonstrated in **Figure 2 (C)** could be used to emphasize this phenomenon. As can be seen, there is no doubt that the increased ash content of handsheets decreased their tensile strength due to the interfiber debonding areas in the handsheet structure. Furthermore, both WWFSs and washed-WWFSs recycled pulp gave handsheets the highest values of brightness and the lowered opacity when applying them to hardwood or softwood pulp at a 1:1 mixing ratio for making handsheets. This is probably because the light could properly travel throughout the handsheet structure with interfacial refraction and scattering at interfiber debonding areas between the surface of cellulosic pulp fibers and that of the inorganic materials retained in the handsheets due to the difference between the refractive indices. With larger or smaller ratios of hardwood or softwood pulp, there is probably less interfacial refraction and scattering due to the increased homogeneity of the handsheet structure with more or less cellulosic pulp fibers, or more or less retained inorganic materials. Moreover, the decreased apparent density of handsheets also resulted in lower opacity because of the transparency of air voids abundant in the handsheet structure (Casey, 1981a).

Figure 2(C) shows the effect of ash content on curl of laser printed handsheets. Even though the increase in ash content of handsheets caused a decrease in curl, handsheets printed on their bottom sides were curlier than those printed on their top sides. This is possibly because the top side of handsheets contained more inorganic materials than the bottom side (Casey, 1981b). These inorganic materials were not hygroscopic and were quite stable in their dimensions even under the thermal condition of laser printing, comparing to cellulosic pulp fibers. As mentioned above, ash content represented the retained amount of inorganic materials, such as fillers and coating pigments, in the handsheets; therefore, it possibly means that both handsheets printed on the top and on the bottom side could be curled to the same level if there was no ash or retained inorganic materials in the handsheets. Both of the linear regression equations in **Figure 2(D)** can be used for addressing this fact, because both equations possess the same intercept, i.e., without any ash or inorganic materials retained in handsheets, both the handsheets printed on only the top and on only the bottom side had the same amount of curl. In this study, the curl of the printed handsheets was irreversible, probably due to the toner pigments fused on the surface.

CONCLUSIONS

Even though the increased amount of WWFSs and washed-WWFSs recycled pulp used for making handsheets decreased the apparent density and tensile strength of handsheets, both hardwood and softwood pulp mixed with washed-WWFSs recycled pulp could produce higher apparent density and tensile strength handsheets than those mixed with WWFSs recycled pulp mostly at the same mixing ratios. This is probably because a lack of good interfiber bonding areas mainly due to inferior swelling and conformability of hornified fibers derived from washed-WWFSs recycled pulp. Most of the various ratios of WWFSs recycled pulp mixed with hardwood and softwood pulp could give slightly higher brightness and opacity handsheets slightly than most of those of washed-WWFSs recycled pulp mixed with the same hardwood and softwood pulp. It seems that inorganic materials, such as fillers and coating pigments, retained in handsheets caused some interfiber debonding areas which contributed to the light scattering of handsheets. Nevertheless, at a 1:1 mixing ratio between WWFSs or washed-WWFSs recycled pulp and hardwood or softwood pulp used for making handsheets, handsheets possessed the highest values of brightness and lowered opacity. This is probably because there was less interfacial refraction and scattering of the traveled light in the handsheets due to the increased homogeneity of the handsheet structure with lager or smaller ratios of WWFSs or washed-WWFSs recycled pulp mixed with hardwood or softwood pulp used to produce the handsheets. The decreased apparent density of handsheets could also result the lowered opacity because of the transparency of air voids abundant in the handsheet structure.

The increase in ash content of handsheets caused the decrease in curl, with laser printing. Handsheets printed on their bottom sides were curlier than those printed on their top sides possibly because the inorganic materials such as fillers and coating pigments, which was demonstrated in terms of ash content, were probably retained more in the top side of the handsheets and they were not hygroscopic and were stable in their dimensions under the thermal condition of laser printing. In this study, it is noteworthy to confirm that without any ash or inorganic materials retained in handsheets, both the handsheets printed on the top and the bottom side had the same amount of curl.

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