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Determination of the Effect of Recycling Treatment on Pulp Fiber Properties by Principal Component Analysis

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ABSTRACT

The effect of recycling treatment on properties of hardwood bleached kraft pulp fibers was determined. Even though the morphological and physical properties of fibers were affected by recycling, there were no significant changes in most of the properties. Therefore, an application of principal component analysis for determining the effect of recycling treatment was attempted and demonstrated in this research. This application could graphically demonstrate the difference between never-recycled and recycled fibers as well as that between the recycled fibers themselves. Furthermore, the results of the analysis could also usefully reveal the correlation between properties of fibers.

Key words: hardwood bleached kraft pulp fiber, principal component analysis, recycling

INTRODUCTION

Paper recycling is increasingly important for the sustainable development of the paper industry as an environmentally friendly sound. With this regard, in the year 2001, the consumption and the recovery rate of wastepaper in Thailand were very fabulously about 1.8 million tonnes and 46 %, respectively (Anonymous, 2001). The research related to paper recycling is therefore increasingly crucial for the need of the industry. Even though there are a number of researches ascertained the effect of recycling treatment on properties of softwood pulp fibers (Cao *et al.*, 1999; Horn, 1975; Howard and Bichard, 1992; Jang *et al.*, 1995), however, it is likely that hardwood pulp fibers have rarely been used in the research operated with recycling treatment. Changes in some morphological properties of hardwood pulp fibers, such as curl, kink, and length of fiber, due to recycling effects also have not been determined considerably. This is possibly because most of the researches were conducted in the countries where softwood pulp fibers are commercial extensively.

Therefore, it is the purpose of the present research to crucially determine the effect of recycling treatment on some important properties of hardwood pulp fibers. An application of principal component analysis (PCA) for this certain purpose was also attempted because PCA can systematically reveal the dominant types of variations between samples. That is, the first few principal components usually cover the important information space for the analysis and are useful for obtaining graphical insight into the dominant patterns of a data table. A complete description of PCA can be found in the work of Martens and Martens (2001).

MATERIALS AND METHODS

According to the standard methods of the Technical Association of the Pulp and Paper

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Industry (TAPPI), USA, handsheets-R0 (never recycled) were produced from a virgin hardwood bleached kraft pulp beaten to a freeness of 480 ml Canadian Standard Freeness (CSF) in a laboratory. Some of them were recycled in the same laboratory without additional chemical and mechanical treatments to produce recycled handsheets-R1 (recycled once), -R2 (recycled twice), -R3 (recycled three times) and -R4 (recycled four times), respectively, following the procedure suggested by Khantayanuwong *et al*. (2002a). During handsheet making, each of R0-, R1-, R2-, R3- and R4-pulp fiber slurry was collected and subjected to analysis for the morphological properties of fibers: curl, kink, and length, with a fiber quality analyzer (FQA, OpTest Equipment Inc., Canada). Changes in some physical properties of fibers, such as crystallinity, swelling capability, and the amount of bound water adsorbed into fibers, were also determined and demonstrated in a previous research of Khantayanuwong *et al*. (2002b). Therefore, some of the quantified properties of fibers used in this study, excluding curl, kink, and length of fiber, were retrieved from the previous research. The effect of recycling treatment on all of the quantified properties was statistically demonstrated and was also analyzed by using PCA with a computer programme.

RESULTS AND DISSCUSION

Table 1 demonstrates changes in the morphological aspects and the physical properties of fibers due to recycling treatment. Each of the properties could be described as the followings. Curl is the gradual and continuous curvature of a fiber and is defined by:

$$\text{Curl index} = (L/l)-1$$

where l is the fiber's end-to-end (projected) length, and L is the fiber contour or curved length. Kink is the abrupt change in the fiber curvature and is defined by:

$$\text{Kink index} = [2N_{(21\text{-}45)}+3N_{(46\text{-}90)}+4N_{(91\text{-}180)}]/L$$

the kink index demonstrated herein is the weighted sum of the number $N_{(X)}$ of kinks within a range of "X" kink angles (Anonymous, 2002). The significant roles of the curl and kink were excellently demonstrated in some researches. For instance, Jordan and Nguyen (1986) revealed that the curl index of fibers was well correlated to the wet-web stretch while kinking was poorly correlated to the wet-web extensibility. Kibblewhite and Brookes (1975) found that the

Table 1 Changes in morphological and physical properties of fibers due to recycling treatment.

Number of recycling	Properties of fibers					
	Curl index	Kink index (1/mm)	Length (length wt., mm)	Aspect ratio	Crytallinity index (%)	Δ H value (J/g)
R0	0.043±0.001	0.77±0.01	0.772±0.016	0.53±0.03	80.9±1.5	148.26±32.45
R1	0.045±0.001	0.77±0.04	0.765±0.020	0.45±0.03	81.2±1.3	143.14±14.99
R2	0.047±0.001	0.81±0.01	0.770±0.001	0.38±0.02	82.0±1.4	131.35±5.38
R3	0.046±0.001	0.79±0.02	0.769±0.013	0.36±0.02	83.0±0.5	122.72±4.97
R4	0.044±0.001	0.74±0.01	0.770±0.009	0.35±0.02	83.7±1.2	119.10±3.55

N.B. each value is denoted at a range of 95 % confidence level; R0, never recycled; R1, recycled once; R2, recycled twice; R3, recycled three times; R4, recycled four times.

high wet strength of kraft pulp sheets was related to pulp bleaching and kinking.

Aspect ratio refers to the swelling capability of wet fiber. A fully swollen fiber with an almost completely round cross-section offers the value of aspect ratio close to 1.0 (Khantayanuwong *et al*., 2002b; Nakamura *et al*., 1983). Crytallinity index is the percent crystalline material in the total cellulose of fibers that could be determined by X-ray diffractometry (Khantayanuwong *et al*., 2002b; Segal *et al*., 1959). The heat of dehydration of the bound water adsorbed into fibers (Δ H value) directly corresponding to the amount of the adsorbed bound water could be measured by differential scanning calorimetry (Bertran and Dale, 1986; Khantayanuwong *et al*., 2002b). Practically, fibers gaining higher crystallinity by recycling normally possess low water adsorbability and perform swelling capability and conformability poorly. Wet recycled fibers with poor conformability consequently could not provide good interfiber contacts during wet sheet forming. (Khantayanuwong *et al*., 2002a).

Even though changes in the physical properties of fibers, i.e., the increase in crystallinity index and the decrease in aspect ratio and Δ H value of fibers, were affected by recycling, there were mostly not significantly different. The effect of recycling treatment on the morphological properties of fibers, i.e., curl, kink, and length of fiber, had also mostly no significance at all. These are possibly because fibers were recycled in the laboratory without any additional chemical and mechanical treatments. The small value of the curl and kink index of fibers was probably due to the inherent nature of short hardwood fibers.

As a result, some of the data analysis methods were crucially necessary for evidently determining the effect of recycling treatment on properties of fibers in this research. That is, according to the aforementioned reason, an application of PCA for data analysis was selected and employed. Figures 1 (a) and 1 (b) show the graphical results of principal component analysis of the data from Table 1, i.e., the PCA score and loading plot of the data, respectively. The dominant patterns of the data were two-dimensionally plotted against the first few principal components.

Figure 1 (a) demonstrates a pattern of relationships between never-recycled (R0) and recycled (R1, R2, R3 and R4) fibers and that between the recycled fibers themselves. As can be seen, according to the first component axis, the effect of recycling treatment was influentially remarkable as the R0- and the R1-fibers were certainly different from other recycled fibers. This possibly means properties of fibers were slightly affected gradually after recycling at least twice. Furthermore, it is also likely that this phenomenon is consistent with the results demonstrated by McKee (1971), i.e., the most rapid decrease in the water retention value of fibers, which was a measure of internal fiber swelling, occurred in the first two recycles. Even though the most difference between the never-recycled and the recycled fibers is that between the R0- and the R4-fibers, the differences between the recycled fibers themselves were also certainly demonstrated according to the second component axis. That is, the R4-fibers were substantially different from the R1-, the R2- and the R3-fibers. This undoubtedly emphasizes that the R4-fibers were affected most by recycling.

Figure 1 (b) shows a pattern of relationships between properties of fibers. As the first component axis corresponded to the physical properties of fibers, the negative correlation between the crystallinity index and the aspect ratio of fibers as well as that between the crystallinity index and the Δ H value of fibers were certainly recognizable. These results are in accordance with those reported by Khantayanuwong *et al*. (2002b), i.e., the correlation between the aspect ratios and the Δ H values of fibers was positively high while that between the crystallinity indices and the Δ H values of fibers was strongly negative. Therefore, as can also be understood from both of the results demonstrated in Table 1 and Figure 1 (b), the increased crystallinity indices and the decreased aspect ratios and Δ H values of fibers due to the effect of recycling treatment could be emphasized. As the second component axis corresponded to the morphological properties of fibers, a close correlation between curl and kink of fiber was considerable. This probably means that these certain properties of fibers were relatively changed simultaneously during handsheet making and recycling.

CONCLUSIONS

Even though properties of hardwood bleached kraft pulp fibers were affected by recycling, changes in the properties were mostly not significant. In this research, an application of PCA for evidently interpreting the effect of recycling treatment was remarkably achieved. Both the difference between never-recycled and recycled fibers and that between the recycled fibers themselves were graphically demonstrated by PCA.

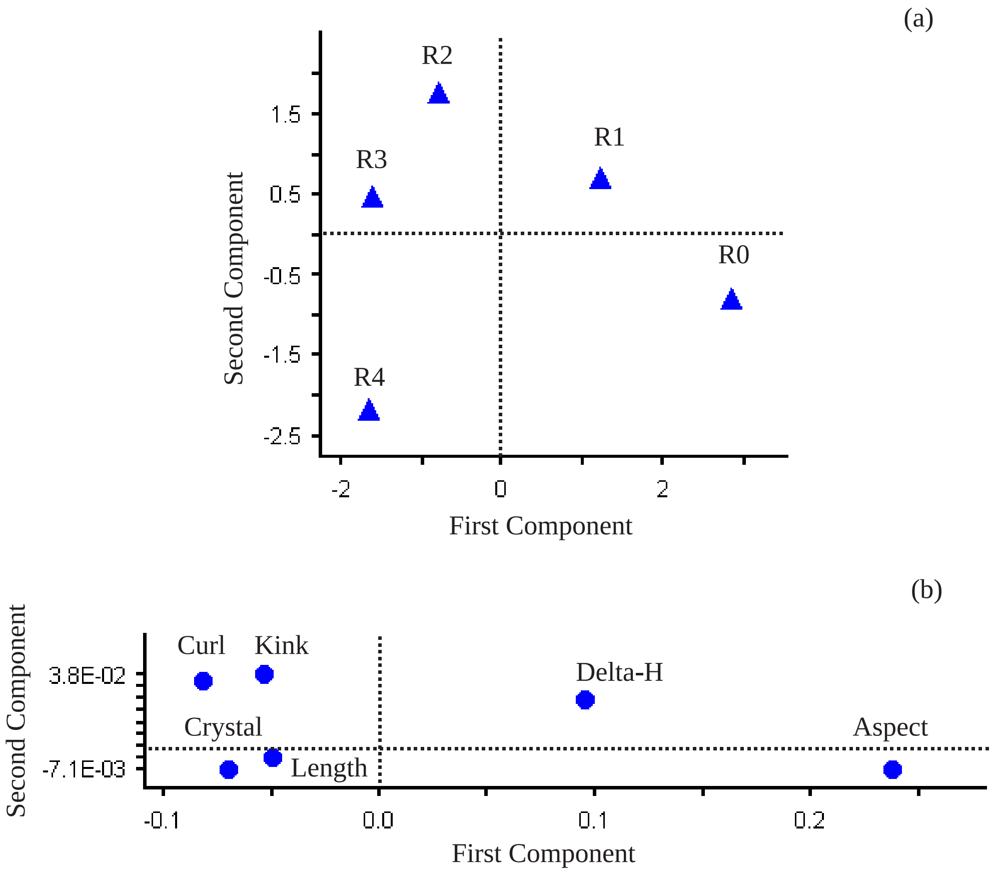

Figure 1 Principal component analysis: (a) a score plot demonstrating a pattern of relationships between never-recycled and recycled fibers and that between the recycled fibers themselves. N.B. R0, never recycled; R1, recycled once; R2, recycled twice; R3, recycled three times; R4, recycled four times. (b) a loading plot demonstrating a pattern of relationships between fiber properties. N.B. Aspect, aspect ratio; Curl, curl index; Crystal, crystallinity index; Delta-H, Δ H value; Kink, kink index; Length, fiber length.

Furthermore, the results of the analysis could also usefully reveal the correlation between properties of fibers.

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