Influence of Fiber Length of the Fractionated Pulp and its Fiber Swelling Capacity on Compressive Resistance and Other Strength Properties of Corrugating Medium Handsheet

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***Abstract*—The objective of this research work was to understand the influence of length and swelling capacity of fractionated pulp fibers on compressive resistance of corrugating medium handsheet and its other strength properties. In this work, the three length fractions of pulp fibers with various degrees of fiber swelling, which was measured with the water retention value (WRV) test, in the range of 1.20-1.70 g/g were used as the fiber samples for making the handsheet with a grammage of 90 g/m^2. These fibers were prepared by fiber fractionating three samples of unbleached softwood kraft pulp with the different freeness levels with the Bauer-McNett classifier. The results showed that compressive resistance of the handsheet, which was measured with the Concora test (CMT), was not increased with an increase in the fiber length of fractionated pulp, but increased significantly with increasing the fiber swelling capacity. On the other hand, the tear strength seems not to be affected by the fiber swelling capacity, but to be significantly affected by the fiber length of fractionated pulp. Other strength properties of the handsheet such as tensile and burst strength were found to be significantly related to the length and swelling capacity of the fibers.**

***Index Teams*—Compressive resistance, strength properties, corrugating medium handsheet, fiber length, fiber swelling**

I. Introduction

Nowadays, corrugated container is one of the most widely used packaging materials in every nearly industry worldwide. This success is because of its versatile, serviceability, stacking strength and low cost of production. Corrugated container is also lightweight, eco-friendly and recyclable, as well as has excellent printability for branded packaging. In Fig. I, a common feature of corrugated container is presented.

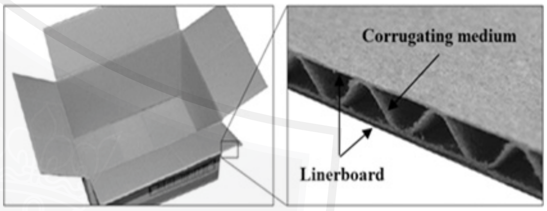

Fig. I. Corrugated paperboard container and its structural components

As shown in Fig. I, corrugated container is made primarily from corrugated paperboard that consists of linerboard and corrugating medium. Linerboard is generally referred to as heavyweight grades of paperboard used as the inner and outer facings of corrugated paperboard. The corrugated medium is a lightweight paperboard that is formed into the wave shape to be used as the corrugated medium layer of the board [1, 2, 3].

Corrugating medium is a critical component of corrugated board production because without the medium, the product would be either a cardboard box or a paper bag. Typically, it has function of contributing the structural rigidity of corrugated board and promoting the cushion characteristic of containers [4, 5]. For this reason, strength properties are very important for the performance quality of corrugating medium [6]. One of the most important strength properties of corrugating medium is compressive resistance which is measured with corrugating medium test or Concora test [3, 6]. The Concora test is a measure of the compression of the paper after corrugating [7]. Fig. II demonstrates the test of compressive resistance of corrugating medium.

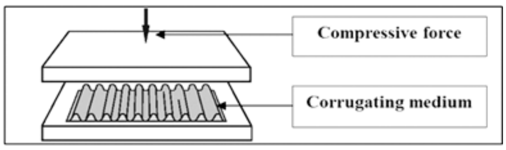

Fig. II. Corrugating medium test

Generally, the result from the Concora test suggests that the compressive resistance depends mainly on the quality of paper material used in the corrugating plant [7]. Because paper is a thin sheet material that is mainly made up of an interlocking network of wood pulp fibers, its quality is basically determined by properties of the fibers used in the papermaking process. The important properties are the morphological properties of pulp fibers such as fiber length, fiber width and cell wall thickness [8, 9, 10]. Of these, the length is one of the most important characteristics of pulp fibers, which is closely related to paper strength properties and is very often used as a measure of pulp quality in the paper industry [11, 12, 13, 14]. In addition to fiber length, fiber swelling capacity, or the fiber ability to retain water in the cell wall, is another fiber property which has long been considered to be an important property in papermaking. It has been reported that the swelling capacity of fibers has a great impact on sheet consideration and interfiber bonding [15, 16, 17].

However, there is noclear information about the influence of fiber properties mentioned above on compressive resistance of corrugating medium. This can cause problems in controlling the stock quality for the corrugating paper, and consequently the performance quality of corrugated medium will be affected. Thus, the aim of the present study was to understand effect that fiber length and swelling capacity of fibers have on compressive resistance of corrugating medium paper. In addition to the compressive resistance, the effect of those fiber properties on other strength properties of the paper was also investigated in this work.

II. Materials and Methods

A. Raw material

The fiber samples used in this study were the three length fractions of pulp fibers, consisting of long, middle and short fraction. The each fraction also contained the three different degrees of fiber swelling. These pulp fibers were prepared by fiber fractionating unbleached softwood kraft pulps with the different freeness levels of 550, 350 and 150 ml (Canadian Standard Freeness-CSF).

B. Fiber fractionation

Fiber fractionation was carried out by using a Bauer-McNett type classifier at the laboratory of pulp and paper technology, department of forest product, faculty of forestry, kasetsart university, Thailand. In the fractionation, the pulp (10.0 g, oven dried) in water of 1000 mL was used. The fractionation was performed using screens of 14-, 28-, and 200-mesh (Tyler standard screen scale) for 20 min. After 20 min, the fibers retained on 14-mesh screen were defined as long fiber fraction, the fibers passed 14-mesh screen but retained on 28-mesh screen were middle fiber fraction, while short fiber fraction was the fibers that were passed 14- and 28-mesh screen but retained on 200-mesh screen.

C. Handsheet forming

Handsheets were prepared at a grammage of 90 g/m^2, and formed in a laboratory handsheet former according to the ISO 5369 standard method. Before the paper strength tests were performed, all the handsheets were conditioned at 23^{o}C and 50% relative humidity in accordance with the ISO 187 standard method for at least 24 h.

D. Pulp and paper properties measurements

In this work, swelling capacity of the fibers was measured with the water retention value (WRV) test in accordance with the SCAN-C 62:00 standard method. Morphological characteristics of the fibers such as length, width and coarseness were measured by using a Fiber Quality Analyzer according to the ISO 16065-1 standard method. Compressive resistance of the corrugated medium handsheet was measured with the concora medium test (CMT) according to the ISO 7263 standard method. The in-plane tensile properties of the sheet including tensile stiffness and tensile strength was measured and calculated following the ISO 1924-2 standard method. The tear strength was measured using an Elmendorf tear tester according to the ISO 1974 standard method. Burst strength of the sheet was measured according to the ISO 2758 standard method. The interfiber bonding strength of sheet was measured by using the inter bond tester (Scott type) in accordance with the TAPPI T 569 om-14 standard method.

E. Data analysis

The data was analyzed using one-way analysis of variance. Duncan's new multiple range test, at 95% confident level, was used for comparing and grouping the mean values.

III. Results and Discussion

F. Pulp properties of the fiber samples

In this work, three samples of the softwood pulp (SW) with a pulp freeness of 550, 350 and 150 ml CSF were used as the raw material for preparing the fiber samples with various lengths and swelling capacities. Table I shows a summary of properties of the pulp fibers obtained from fiber fractionation of the SW pulp in the Bauer-McNett classifier that was performed using screen of 14-, 28- and 200-mesh. Results from Table I show that there was no significant difference in the fiber length and fiber width of the fractionated pulp in the same length fraction. The average fiber length for long fraction was about 3.01 mm, while the middle and short fraction was about 2.09 and 1.14 mm, respectively. The mean width of the fibers was about 42.59 µm for the long fraction, 41.48 μm for the middle fraction and 38.58 μm for the short fraction. Additionally, the results indicate that the swelling capacity, which was measured with the WRV test, of each fiber sample used in this study had statistically significant difference. Swelling degree of the fractionated pulp was in the range between 1.20 and 1.70 g/g. Based on the results obtained, the coarseness value, which indicates the cell wall thickness, showed significant difference in the pulp having different length fraction. The fractionated fibers with the longest length had the highest value of coarseness. As can be observed, the coarseness value was decreased as the swelling capacity of fractionated pulp increased. This result could be explained by the water retained by capillarity inside the lumens. When the fibers contain more total volume of lumen (lower wall thickness), they have higher WRV value.

Table I
Pulp properties of the fiber samples

Raw materials	Length fraction	Properties of the fractionated fibers			
		Length (mm)	Width (μm)	Coarseness (mg/g)	WRV (g/g)
SW500	Long (R14)	3.01a	42.93a	0.278a	1.22i
SW350	Long (R14)	3.00a	42.63a	0.272b	1.30h
SW150	Long (R14)	2.99a	42.20a	0.263c	1.35f
SW500	Middle (P14/R28)	2.10b	41.53b	0.216d	1.34g
SW350	Middle (P14/R28)	2.10b	41.47b	0.204e	1.38d
SW150	Middle (P14/R28)	2.08b	41.43b	0.199f	1.46c
SW500	Short (P14,28/R200)	1.15c	38.83c	0.180g	1.35e
SW350	Short (P14,28/R200)	1.14c	38.60c	0.164h	1.58b
SW150	Short (P14,28/R200)	1.14c	38.30c	0.155i	1.70a

G. Mechanical properties of the handsheets

Fig. III shows the effect of average fiber length and fiber swelling capacity, which was measured with the WRV test, of the fractionated pulp on the compressive resistance of the handsheet, which was measured with the Concora test (CMT). The figure shows that compressive resistance of the handsheet was not increased with increasing the average fiber length of fractionated pulp. It seems that the CMT value was mainly depended onthe fiberswelling capacity. As reported by Whitsitt and Sprague [18], the compressive resistance (CMT) is a function of elastic modulus of the sheet. In this study, it was found that when the average length of pulp fibers increased, the specific elastic modulus of the sheets (elastic modulus divided by sheet density)was not increased, as shown in Fig. IV. This phenomenon could be explained from Fig. V. In Fig. V, the effect of average fiber length of fractionated pulp and itsfiber swelling capacity on the bonding strength, which is considered as the main factor controlling the elastic modulus of sheet [19], is illustrated. As shown in Fig. V, the bonding strength of handsheets was significantly decreased when the average fiber length of fractionated pulp was increased. This might be because the fractionated pulp with longer length had the higher coarseness value compared to the fibers with shorter length (Table I). The high coarseness value usually results in the fibers with low conformability and poor bonding ability, and therefore the bonding strength is decreased. Based on these results, it could be concluded that the swelling capacity of fractionated pulp was a main contributing factor of compressive resistance of the corrugating medium handsheet.

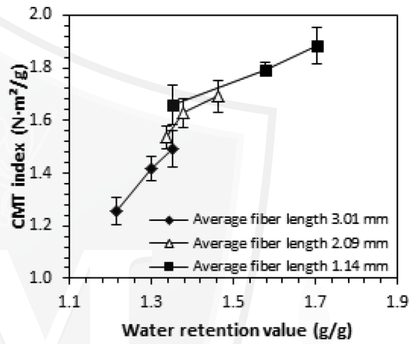

Fig. III. Compressive resistance (CMT) as function of fiber length and fiber swelling capacity of the fractionated pulp

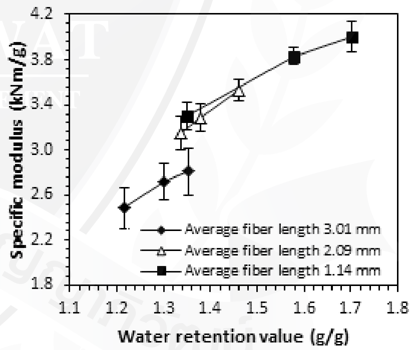

Fig. IV. Effect of fiber length and fiber swelling capacity of the fractionated pulp on the specific modulus of handsheets

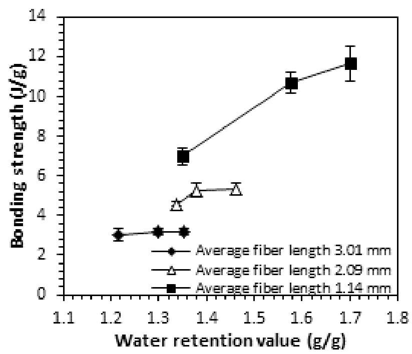

Fig.V. Effect of fiber length and fiber swelling capacity of the fractionated pulp on the interfiber bonding strength of handsheets

Tensile strength is one of the most important strength properties of paper and paperboard, which mainly depends on fiber bonding, fiber length and intrinsic fiber strength [19]. Therefore, it was found that when the swelling capacity of fractionated pulp was increased, the tensile index of handsheets was significantly increased (Fig. VI), which was due to its positive effect on the interfiber bonding strength in paper (Fig. V). Moreover, it could be observed from Fig. VI that at the lowest swelling degree, the long fiber fraction did not provide higher tensile strength of the sheet than the middle and short fiber fraction. This might indicate that the average length of pulp fibers had less effect on the sheet strength when the fibers had the poor bonding potential. At the similar swelling capacity, the fractionated pulp with longer fiber length generated the handsheets with superior tensile strength. This demonstrated the long fiber fraction had higher resistance to be deformed plastically under tensile force compared to the middle and short fiber fraction (Fig. VII)

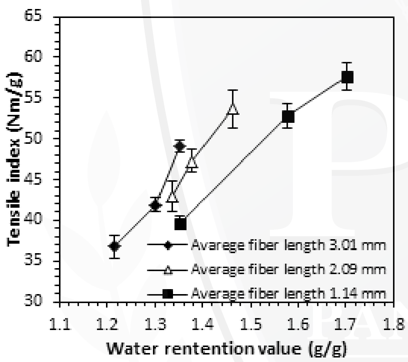

Fig.VI. Effect of fiber length and fiber swelling capacity of the fractionated pulp on the tensile strength of handsheets

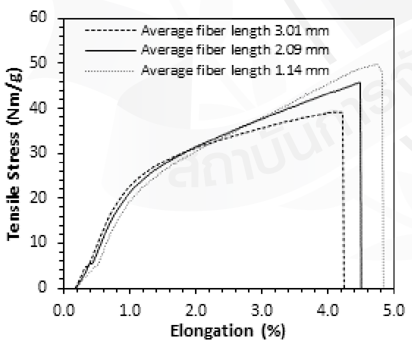

Fig. VII. Load-elongation behavior of the sheets made from the three different length fraction of fractionated pulp with similar swelling degree

Fig. VIII shows the effect of length and swelling capacity of the fractionated pulp fibers on the burst index. Basically, the burst strength depends on the fiber length and fiber bonding. Hence, it was not surprising that the burst index of handsheets was found to be greatly improved with increasing the fiber length of fractionated pulp and its swelling capacity.

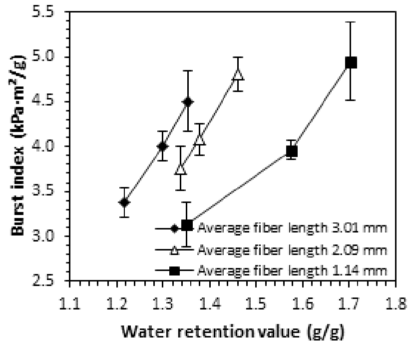

Fig.VIII. Effect of fiber length and fiber swelling capacity of the fractionated pulp on the tensile strength of handsheets

Fig. IX shows the effect thatthe fiber length and fiber swelling capacity of fractionated pulp have on the tear index. According to Paavilainen[13], tearing resistance of paper is a function of intrinsic fiber strength, fiber length and bonding degree of fibers. Therefore, the handsheets made from the long fiber fraction had higher tear index compared to those made from the middle and short fiber fraction, which was becausethe long fiber fraction had higher length and coarseness (Table I). Although Paavilainen [13] has explained that tear strength is also related to the fiber bonding degree in paper, in the present study we found that the increase in the swelling capacity of fractionated pulp did not result in the sheets with increased tear strength. This means that the fiber length had much stronger impact on the tear index more than the fiber swelling capacity did.

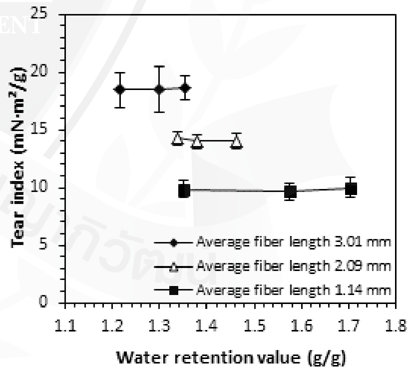

Fig. VIII. Effect of fiber length and fiber swelling capacity of the fractionated pulp on the tensile strength of handsheets

IV. Conclusion

In this study, effect of fiber length and fiber swelling capacity of the fractionated SW pulp on compressive resistance and other mechanical properties of corrugating medium handsheet was examined. The results showed that compressive resistance of the corrugating medium handsheets, which was measured with the Concora test, was not increased with increasing the average fiber length of fractionated pulp. This was because increasing the average length of fractionated fibers did not result in the increased elastic modulus, which is one of the effective parameters for the compressive resistance (CMT). Thus, the CMT of handsheets was found to bemainly dependent on the fiber swelling capacity of fractionated pulp. On the other hand, tear strength of the handsheet was found not to be dependent on the fiber swelling capacity, but to be dominantly controlled by the fiber length of fractionated pulp. Other strength properties of handsheets such as tensile and burst strength were found to be affected significantly by the fiber length and fiber swelling capacity of fractionated pulp.

V. Acknowledgements

The authors would like to thank Graduate School, Kasetsart University for providing part of the funding for this research. The experimental work of this research was carried out at Laboratory of Pulp and Paper Technology, Department of Forest Products, Faculty of Forestry, Kasetsart University which is gratefully acknowledged.

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