FRACTIONATION OF OLD CORRUGATED CONTAINERS FOR MANUFACTURE OF TEST LINER AND FLUTING PAPER

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Old corrugated container (OCC) pulp was fractionated and it was found that the longer fiber fraction represented 76.54% and the short fiber fraction – 21.3% of the OCC pulp. The fiber length was 1.22 mm for the long fiber fraction and 0.6 mm for the short fiber, which was longer and shorter, respectively, than the fiber length of the whole OCC pulp (0.95 mm). In addition to fibers in pulp, the cellulosic microparticles that pass through a mesh screen or a perforated plate with a hole diameter of 76 µm, called fines, also have an impact on the properties of the final paper product. The fines content in both longer and shorter fiber fractions was lower than in the whole OCC pulp, consequently, drainage resistance (°SR) in the longer fiber fraction decreased to 14 from 21 in the whole OCC pulp. The air permeability and papermaking properties of the longer fiber were higher than those corresponding to the whole OCC and shorter fiber pulp. Therefore, the longer fraction of pulps can be used to manufacture test liner products and the shorter fiber fraction – for fluting paper.

Keywords: old corrugated container, long fiber, short fiber, fines, porosity, strength properties

INTRODUCTION

Nowadays, the recycling of waste paper is steadily increasing in the world, due to environmental concerns, population growth and the shortage of wood supply. One consequence of increased recovery and utilization is that the fibers will be reused more times. The average number of times of fiber use in Europe is 3.5 times and 2.4 times for the rest of the world. Although the fibers, even after several cycles, will be good enough for papermaking, the handling, *e.g.* slushing, pumping *etc*., will create fine material, reducing both pulp strength and yield for each cycle.

Old corrugated container (OCC) – a sustainable and low-cost paper product – has been widely used as a packaging material for shipping and handling of different products. OCC paper is the most significant category of waste papers for recycling. It has been claimed that the strength of such recycled fibers is not sufficient to meet the industry's demand; thus, the strength should be improved.

Hornification is the major consequence of loss in swellability of paper during recycling. It also reduces interfiber bonding potential in recycling through the stiffening of the fibers.[1] Problems become worse at very low or high humidity. Brittleness increases at low humidity, making the paper less resistant to damage, and both stiffness and strength decrease at high humidity.[2] The lost potential of recycled pulps can be improved by beating or refining, chemical treatment, blending with virgin pulp and fractionation.[3-8]

Bhardwaj *et al*. applied chitosan on the surface of recycled fibers to improve important paper properties, such as strength and barrier properties.[4] Cicekler *et al*. found that the addition of butylamine during OCC recycling improved optical and strength properties of recycled pulp.[6] Rudi *et al*. conducted layer-by-layer (LbL) treatments to assemble consecutive cationic and anionic starch layers on the fibers of OCC pulp and mixed treated OCC with refined pulp to improve the mechanical properties of paper. Thus, tensile index of 44.5 N.m/g, Scott bond value of 149 J/m^2, 32 mN RCT, and 245% strain at break were achieved under optimal conditions of 16 min refining time and the addition ratio of 17.6% LbL treated pulp respectively.[7] The application of nanosilica with cationic starch increased fines retention up to 39% and drainage up to 42% in high basis weight recycled paper produced from OCC, therefore improving machine speed, reducing energy consumption and increasing the productivity of the whole papermaking system.[8]

Freeland and Hrutfiord observed different behavior when OCC was treated with sodium hydroxide. Under the optimum conditions, the short span compression index of OCC increased by 10.6% and that of linerboard increased by 20.4%.[9] Miao *et al*. treated hornified fibers with NaOH/urea aqueous solution precooled to -13 °C to disassemble inter- and intramolecular hydrogen bonds.[10] This process significantly improved fiber swelling ability and physical properties of the resulting paper sheets. The strength properties of recycled fiber can be improved by blending with virgin pulp.[11] Zanuttini *et al*. used alkaline peroxide treatment of recycled fiber and found out that the delignifying effect was enhanced by peroxide addition in alkali, which reduced freeness and improved the papermaking properties.[12]

Fractionation is a technique to enhance the quality of the recycled fiber.[13] Recycling-induced fiber degradation can be mitigated by fractionating the fibers into a superior longer fiber fraction, an inferior shorter fiber fraction and fines. Superior fibers can be then employed to create higher quality paper. Inferior fibers, on the other hand, can be utilized to produce lower grade paper. Fiber fractionation can also increase porosity by removing some of the fines and short fibers, enabling the pulp to be refined to a higher strength. The resulting long fiber pulp had significantly higher porosity after being laboratory refined with a PFI mill to a target TEA, and a super-porous, high-strength pulp.[14] On the other hand, the short fiber pulp exhibited low freeness and minimal porosity, making it better suited for less demanding paper grades, suitable for printing considering its smooth surface.

In this investigation, old corrugated container (OCC) was fractionated into different fiber fractions according to the Bauer McNett fibre classification. The fractionated pulp fiber was characterized by a Fiber Quality Analyzer (FQA), and in terms of drainage resistance and ash content. Subsequently, handsheets were prepared using the longer and the shorter fiber fractions and papermaking properties were evaluated.

EXPERIMENTAL

Materials

OCC was collected from the market, it was of mixed origin, having been manufactured in different countries.

Fractionation of OCC pulp

The obtained commercial OCC was torn into pieces ranging in length from 3 cm to 5 cm and soaked in distilled water for 24 hours. The soaked materials were disintegrated for 15 minutes in a disintegrator. Following disintegration, 24 g of oven dried (o.d.) OCC pulp was fractionated for 20 minutes with a fiber classifier (Xell and Einlehner Instruments, Austria), according to TAPPI T233 cm-95 (1995). For the fractionation, screens of five different sizes were used: 16-mesh, 30-mesh, 50-mesh, 100-mesh, and 200-mesh. The fractionated pulps were collected and stored at room temperature until further testing. The weight percentage of each fraction (based on the original raw material) was determined by drying the sample to a constant weight at 105 ± 2 °C. The fractionated pulps were converted into two fractions named OCC long fibers and OCC short fibers. OCC long fibers were the mixture of 16-mesh, 30-mesh, 50-mesh screen size fibers and OCC short fibers were the mixture of 100-mesh and 200-mesh screen size fibers.

Fiber quality analysis

The fiber length, width, curl index, kink index, coarseness and fines content of the whole OCC pulp, and fractionated OCC long and short fiber fractions were measured by a Fiber Quality Analyzer – 360, OpTest, Canada.

Evaluation of fractionated pulpsheet

The whole OCC pulp, and fractionated OCC long and short fiber fractions were beaten in a Valley beater, at different drainage resistance (°SR) value, and handsheets of about 60 g/m^2 were made in a Rapid Kothen Sheet Making Machine. The sheets were tested for tensile (T494 om-96), burst (T403 om-97) and tear strength (T414 om-98) according to TAPPI Standard Test Methods.

The ash content in the whole OCC pulp, and fractionated OCC long and short fiber fractions was determined in accordance with Tappi Test Methods T211 os76.

RESULTS AND DISCUSSION

Fiber fractionation

Fractionation is a process by which fiber streams are split into 2 fractions, a longer fiber fraction and a shorter fiber fraction, thus allowing improvement of fiber strength by refining and dispersion of the long fiber fraction, and reduced stock variability.

OCC pulp was fractionated into different fiber mass fractions and results are shown in Table 1. The fibers retained on the 16, 30, 50-mesh screens were defined as long fiber. Approximately 77% of the fibers of OCC pulp were long fibers. Individually, 22.8%, 32.04% and 21.75% of fibers were retained on the 16, 30, 50-mesh sieves, respectively, and altogether they represented the long fiber fraction in the OCC pulp. The fiber fractions retained on 100-mesh and 200-mesh sieves were considered as the short fiber fraction in this pulp, which amounted to 13.24% and 9.1%, respectively. Therefore, the long fiber fraction was 77.59% and the short fiber fraction was 22.41% of the OCC pulp. The fiber fraction depending on the fiber length varies for different OCC. In a previous study, it was observed that the American OCC had 60% longer fiber fraction, while Chinese OCC had 35% longer fiber fraction.[15] The fines are defined as the fibers that can pass through the smallest mesh screen (200-mesh), which was not taken as fiber furnish.

The ash content in recycled paper significantly decreases its strength due to the negative impact of ash on fiber bonding. The separation of low bonding components from the fibers can increase fiber quality of recycled pulp with good bonding ability. Additionally, removing ash not only enhances the strength properties of recycled paper, but also give the possibility to utilize the ash by-product elsewhere. The ash content in the whole OCC was 16.78%, which decreased to 2.65% in the long fiber fraction and to 8.36% in the short fiber fraction (data are not shown). A major portion of ash was removed through the 200-mesh screen. Bjärestrand and Alfthan obtained 30% higher short span compression strength and tensile stiffness, as compared to the feed, by removing some of the ash from the pulp.[2]

Table 1
Fiber fractions of OCC pulp

16 mesh (~%)	30 mesh (~%)	50 mesh (~%)	100 mesh (~%)	200 mesh (~%)
22.8	32.04	21.7	13.2	8.1

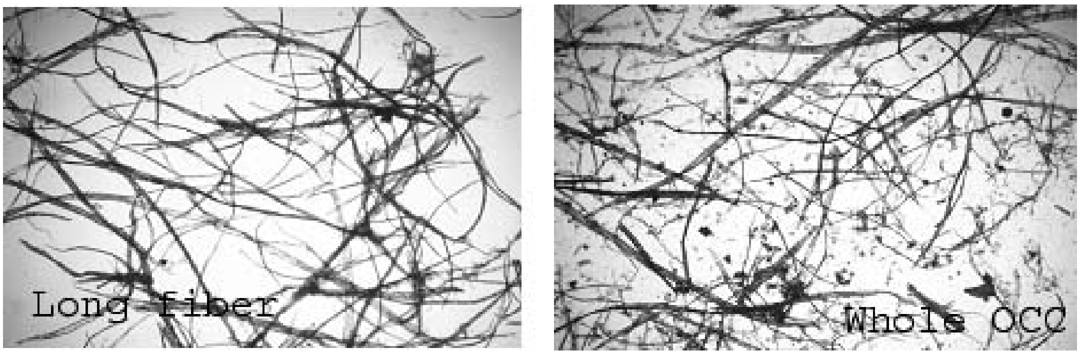

Figure 1: Fiber morphology of (a) fractionated OCC and (b) whole OCC

Fiber quality analysis

Microscopic images of OCC long and short fiber fractions are given in Figure 1. The OCC long fiber fractions were very well organized and having lower fines contents, while the short fiber fractions had greater fineness because of the shorter fibers. The whole OCC pulp fiber and the two fiber fractions were analyzed in the FQA to understand the fiber characteristics, such as length, width, fines, curl, kink *etc*. and results are shown in Table 2. The fiber length was 1.22 mm for the long fiber fraction and 0.6 mm for the short fiber fraction, which were longer and shorter, respectively, than the value for the whole OCC pulp (0.95 mm). The curl index and kink of the long fiber fraction were lower than those of the short fiber fraction, and therefore, it is expected to produce stronger paper in subsequent pulp processing. Cai *et al*. observed that the curl index of fiber decreased with decreasing fiber length, but it then increased because of the presence of impurities in the short fiber fraction.[15] The fines content in both long and short fiber fractions was lower than in the whole OCC pulp.[16] This is because, in the fractionation process, fines passed through the 200-mesh sieve and did not remain in the two fractions. Therefore, drainage resistance (°SR) in the longer fiber fraction decreased to 14 from 21 in the whole OCC pulp. The higher value of °SR of the whole recycled OCC pulp can be explained by its higher fines content. The fines increase the specific surface area and fill the voids between the fibers, therefore do not contribute to fiber to fiber bonding. Lindström *et al*. fractionated OCC pulp slurry, which removed about 15% fines, and reduced drainage resistance. Thus, fractionated OCC pulp can be used in high speed machines.[17]

Table 2
Fiber quality of OCC and fractionated OCC pulp

Fraction	Length weighted (mm)	Fiber width (µm)	Curl index (%)	Coarseness (mg/m)	Kink index (Nm^{-1})	Fines content (%)
Long fiber	1.22	20.48	10.14	0.2985	1.75	10.6
Short fiber	0.60	19.9	13	0.285	2.28	23.9
Whole OCC fiber	0.95	19.48	9.285	0.189	1.69	37.1

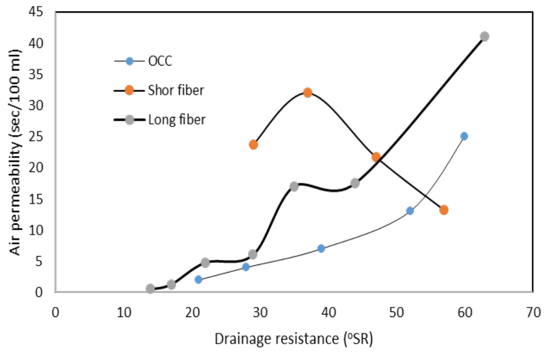

Figure 2: Porosity of OCC and fractionated long and short fiber pulps

Air permeability analysis

As shown in Figure 2, the air passing time of pulp sheets prepared from the short fiber fraction was higher than that of the pulp sheet made from the long fiber fraction. Higher air passing time means lower porosity of the paper. The air passing time from the pulp sheet from the whole OCC and the longer fiber fraction increased with the beating degree, but the air passing time in the pulp sheet from the short fiber fraction initially increased and then decreased with further increasing beating degree. This means the paper pore structure became smaller and the paper tightness increased with the beating degree, which was attributed to the increase in bonding and networking of fibres and newly generated fines. On the other hand, the shorter fibers lost their bonding potential during prolonged beating. Gulsoy *et al*. observed that the air permeability increased when shorter fiber was mixed with longer fiber. Thus, the longer fiber fraction would be suitable for manufacturing sack paper.[18]

Papermaking properties

The fiber quality of recycled pulp regulates the paper quality. However, it is difficult to maintain constant quality of OCC, because of the wide range of paper used for manufacturing corrugated liner board and corrugated medium. The liner produced from recycled fiber is denoted as test liner and divided into four grades (CEPI 2015), with test liner 1 having the highest quality and test liner 4 – the lowest.[19] The grades are determined by reaching minimum requirements for either tensile index or burst index. The strength properties of test liner 1 should be as high as for virgin fiber based kraft liner.

Figures 3-5 show the papermaking properties with respect to the drainage resistance of the short and long fiber fractions and of the whole OCC pulp. As expected, the tensile index increased with the beating degree. The long fiber fraction showed a very good tensile index, as compared to the short fiber fraction and the whole OCC pulp.

At 35 °SR value, the tensile index of the long fiber fraction was 43 N·m/g, while for the short fiber fraction, it was 21 N·m/g only. Nazhad showed that the paper strength of refined unfractionated OCC fiber pulp was higher than that of recombined stock.[20] Nazhad and Awadel-Karim,[1] and Sloane and Weinberg[21] also reported that the paper strength of the whole OCC refined pulp was better than that of a mixture of refined long fiber fraction and short fiber fraction. Based on these previous studies, the recombination process is not practical and hardly could be recommended for paper or board manufacturers as an option for upgrading OCC pulp.

Burst index is an important property for corrugated container. This strength characteristic indicates the resistance of the container to internal and external mechanical stresses. As shown in Figure 4, the burst index increased with the beating degree, as the tensile index, and the long fiber fraction showed higher burst index than the short fiber fraction and the whole OCC pulp. In the initial stage, there was no difference of burst index between the short and the long fiber fractions. At 35 °SR value, the burst index of the long fiber fraction was 2.5 kPa.m^2/g, while that of the short fiber fraction and whole OCC was 1.2 kPa.m^2/g and 1.7 kPa.m^2/g, respectively. Sheikhi *et al.* mixed OCC pulp with virgin bagasse pulp for making fluting paper, and obtained a burst index of 1.62 kPa.m^2/g at the OCC to bagasse pulp ratio of 50:50.[22]

Figure 5 shows that handsheets made from the long fiber fraction had higher tear index, which increased with the beating degree up to 17 °SR. Further increase of beating degree decreased the tear index. The maximum tear index of the longer fraction fiber was 17.5 mN.m^2/g at 17 °SR value, which decreased to 7.76 mN.m^2/g at 35 °SR value. Meanwhile, the maximum tear index of the shorter fiber fraction was 5.56 mN.m^2/g at 37 °SR.

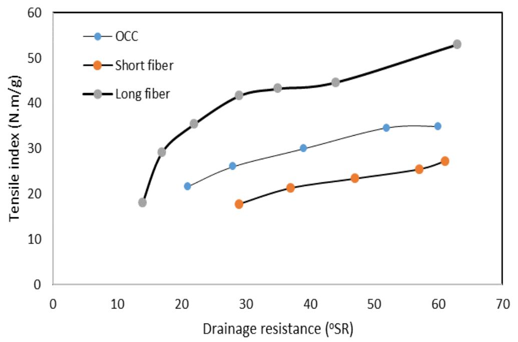

Figure 3: Tensile index of OCC and fractionated pulps

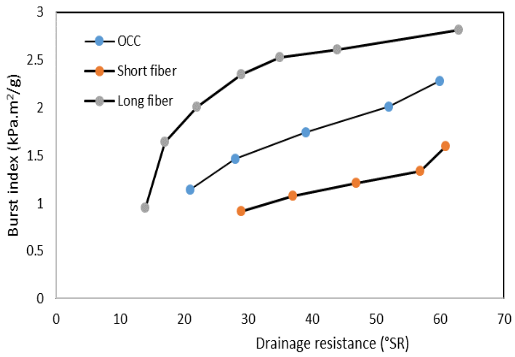

Figure 4: Burst index of OCC and fractionated pulps

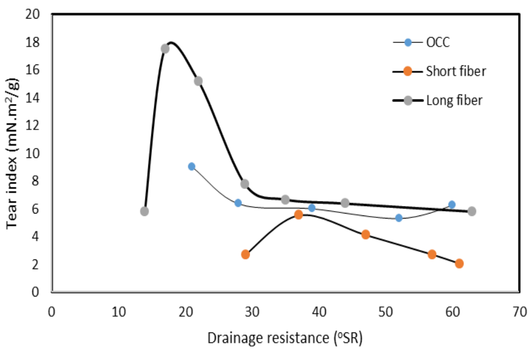

Figure 5: Tear index of OCC and fractionated pulps

Folding endurance analysis

Folding endurance is a physical property of paper that measures how well it can survive folding and unfolding without breaking. In other words, it determines how many times the paper can be folded until it breaks. Cardboard is folded to boxes in different shapes. Therefore, this is an important property for liner. Folding endurance of paper is determined as the number of the double folds required to break a test piece. Table 3 shows the folding endurance of the whole OCC, long and short fiber fraction pulps at different beating degrees. The folding endurance increased with the beating degree, and the longer fiber showed the best folding endurance. At the beating degree of 58-62 °SR, the folding index of the whole OCC pulp was 1.4625, which increased to 2.102 after separating shorter fibers and fines. On the other hand, the folding index of the short fiber fraction was only 0.301.

Table 3
Folding index of OCC and fractionated long and short fiber pulps

Beating degree (°SR)	Folding index		
	OCC pulp	Long fiber	Short fiber
26-30	1.04	1.63	0
39-43	1.22	1.61	0
58-62	1.4625	2.102	0.301

CONCLUSION

OCC fractionation decreased the ash content in recycled pulp. The long fiber fraction had a good papermaking strength, unlike the short fiber fraction. The tensile and burst indices of the long fiber fraction were much higher than those of the short fiber and the whole OCC pulps at any beating degree. Thus, the long fiber fraction can be used in the manufacture of test liner, while the short fiber fraction – for fluting paper. The pulp sheet from the long fiber fraction had higher porosity than the short fiber fraction and whole OCC pulps. Therefore, the long fiber fraction can also be used in the production of sack paper.

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