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# Characterization of Recycled Fiber Material Made from Liquid Containerboard (LCB) and/or Old Corrugated Containers (OCC) – Evaluation of its Use by a Handsheet Study

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Packaging materials for packaging liquid goods may contain over 75% virgin bleached fiber material that can be used to offset and or upgrade existing board products.

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This laboratory handsheet study investigated the use of recycled old corrugated container and liquid container board which is currently not utilized from the recycling stream for paper board production.
Both fiber materials were repulped for 30 minutes at a pH of 10, a temperature of 150°F (65.6°C), and 1% Oxone addition based on fiber content under laboratory conditions. Handsheets were produced from unrefined and refined fiber materials with a freeness level of 400 ml.
Handsheets containing fiber material from liquid containerboard packaging showed an up to 3-fold higher mechanical paper properties if refined for burst, tensile, short compression strength, tensile energy adsorption and elongation. Tear Index values and 0-Span values were comparable, whereas porosity decreased with refining the old corrugated container and liquid container board fiber material.
Handsheets optical properties, L*, a*, b*, whiteness, and brightness, increased gradually from a dark brown color to a lighter brown color based on increasing LCB fiber content. Refined old corrugated container and liquid container board fibers resulted in a slightly darker color value, due to the virgin bleached softwood fibers used to manufacture the liquid container board paper product.
Opacity measured of this study showed a 100% value for all manufactured handsheets.
It can be concluded that utilizing fiber material from recycled liquid containerboard packaging at an addition level of up to 25% can enhance board paper products mechanical and optical requirements. Additional benefits might foster increased sustainability, biodegradability, and eco-efficiency of the paper board product.
However, more research is needed to assess the optimum liquid container board fiber addition for board products including processing and manufacturing conditions, including analyses of economic benefits regarding improvement of mechanical and optical properties of the resulting board product.

*Keywords: Aseptic packaging materials; beverage carton; liquid container board; milk carton; paper board; paper properties; recycling; repulping.*

## 1. INTRODUCTION

Liquid Container Board (LCB) is a paper product that is used in the food industry to pack perishable items such as milk, juices, fruits and other perishable items [1] to prevent microorganisms from entering the product [2].

Fig. 1 shows a typical composition of LCB used in the North American market containing paperboard as a based material coated with multiple layers of Polyethylene (PE).

Environmentally friendly LCB material is increasingly used in liquid food products by food manufacturers for packaging purposes. It can be assumed that this material is collected in greater quantities through the recycling stream in the future and therefore becomes available for reuse in paper and board manufacturing processes. An increased use of LCB material requires to develop new solutions to utilize fiber material, Polyethylene (PE) film and other material that may make up the LCB product.

The 2021 Scrap Specification Circular (SSC) of the Industry of Scrap Recycling Industries (ISRI) 2021 defines the material as Grade N0. 52 [2-4]. It can be considered a composite material and can contain according to the ISRI-SSC includes generally no less than 70% bleached chemical fibers, up to 24% PE film, up to 6% Aluminum, and prohibitive material and outthrows may not exceed 2% and 5% respectively [1-8].

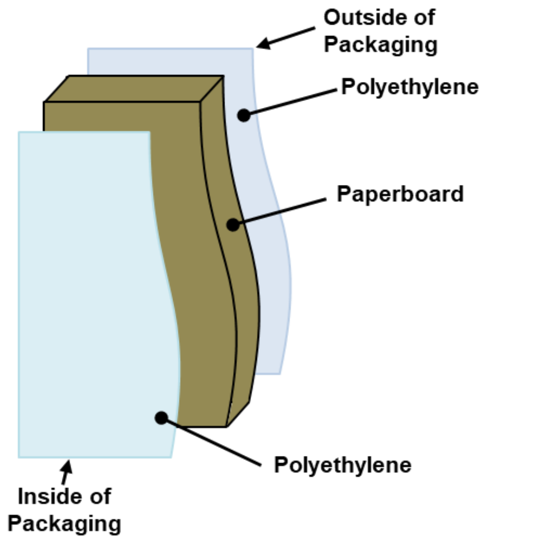



**Fig. 1. Illustration of North American moister resistant liquid packaging board [1]**

In North America virgin bleached chemical fibers are used to manufacture the base paperboard layer, which represents the most valuable material for recycling [1]. The PE layer at present time cannot be used as raw material for new food packaging and in most cases is downcycled and or used as byproduct for various composite materials [6,8].

Utilizing LCB material from the recycling stream in the manufacturing process can lead to a leaner paper production as well as increased sustainability, biodegradability, and eco-efficiency [2,9-11], minimizing production cost and comply with environmental regulations.

The following manuscript describes research work executed for the recovery of fiber material from LCB and its use in Old Corrugated Container (OCC) board packaging material. A laboratory repulping procedure for the recovery of fibers from the LCB and recycled OCC material was used. Recovered fibers were used as unrefined and refined products to produce handsheets with various compositions in order to investigate the optimum addition of LCB and OCC material for board packaging materials.

## 2. MATERIALS AND METHODS

The following materials and methods were used for the laboratory evaluation on recycling LCB for board paper applications.

### 2.1 Materials and Equipment

For this laboratory study LCB material from recycled orange juice containers containing typically 64 fluid ounces (fl. oz.). (1.89 l) were used. Recycled OCC material was obtained by using shipping boxes from Amazon, because these boxes do not contain large images printed on the boxes. Both materials were collected by the researchers in their respective households.

As pulping chemical Oxone ($2KHSO_5KHSO_4K_2SO_4$) was used acquired from Beantown Chemicals in granular form based on Oven Dry (OD) content.

Sodium Hydroxide (NaOH) pellets acquired from Sigma Aldrich were used to adjust to prepare a 20% NaOH solution that was used to adjust the pH.

Low pressure steam at a pressure of 100 psi (689.48 kPa) was used to adjust the temperature of the laboratory repulping.

Temperature and pH were measured with a portable Milwaukee MW102 pH/temperature meter as well as a Therm-Pro handheld temperature probe.

A Laboratory Pulper with a 1 hp (0.75 kW) motor with a maximum repulping capacity of 3 gallons (11.35 liter) was used.

The repulper power consumption was measured with a PN2000 Electronic monitor.

The repulped LCB material was screened using a No. 5 mesh (4 mm) 200 mm diameter screen pan. The usable fiber material was then recovered using a large screening box with a No. 150 mesh (105 μm) screen lining.

### 2.2 Testing Methods

For this research project the following testing methods of the Technical Association of the Pulp and Paper Industry (TAPPI) were used:

Beating of pulp (Valley beater method) in accordance to T 200 sp-06 “Laboratory beating of pulp (Valley beater method)” [12].

Handsheets were prepared according to TAPPI T 205 sp-12, “Forming handsheets for physical tests of pulp” [13]. Physical testing of handsheets was performed in accordance with T 220 sp-06, “Physical testing of pulp handsheets” [14]. The Zero span breaking length was measured using T 231 cm-96, ‘Zero-span breaking strength of pulp (dry zero-span tensile)” [15]. Consistency of the pulp suspensions was measured with TAPPI T 240 om-07 “Consistency (concentration) of pulp suspensions” [16]. Freeness of pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09 “Freeness of pulp (Canadian standard method)” [17]. Conditioning of the paper samples was done according to T 402 sp-08, “Standard conditioning and testing atmospheres for paper, board, pulp handsheets, and related products” [18]. Burst Strength was measured in accordance with T 403 om-02 :Bursting strength of paper” [19]. Basis weight was measured with T 410 om-08. “Grammage of Paper and Paperboard (weight per unit area)” [20]. Thickness/Caliper of paper was measured in accordance with T 411 om-10, “Thickness (caliper) of paper, paperboard, and combined board” [21]. The moisture content of pulp was determined by T 412 om-06 “Moisture in pulp, paper and paperboard” [22]. The hand sheets tear resistance was measured with T-414 om-98, "Internal tearing resistance of paper (Elmendorf-type method)" [23].

Air resistance was measured with T 460 om-02 "Air resistance of paper (Gurly method)" [24].

Tensile strength properties were measured according to T-494 om-01. Tensile properties of paper and paperboard (using constant rate of elongation apparatus) [25].

Short span compressive strength was measured according to T 826 pm-92 "Short span compression strength of containerboard" [26].

Brightness was measured according to ISO 2470 "Paper, board, and pulps - Measurement of diffuse blue reflectance factor – Part 1: Indoor daylight conditions (ISO Brightness) [27]. Opacity was determined according to ISO 2471:2008 Paper and Board: Determination of Opacity (Paper Backing) – Diffuse Reflectance Method [28].

Whiteness/Color was measured according to ISO 11476:2016 "Paper and Board – determination of CIE Whiteness, C/2° (Indoor Illumination Conditions)" [29].

## 2.3 Laboratory Repulping

Laboratory repulping was done with a 0.75 kW (1.0 hp), laboratory pulper, shown in Fig. 2, that can process a maximum liquid volume of 3 gallons (11.35 liter).

Repulping of recycled LCB and OCC fiber material is based on an study by Dölle, Jeva and Iribarne in 2022, that revealed that repulping for 30 minutes at a solids content of 4.5% under a pH of 10, a temperature of 150°F (65.6°C), and an 1% Oxone addition achieved optimum results [4].

**Fig. 2. Low consistency laboratory repulper [1]**

Laboratory repulping illustrated in Fig. 3, simulates a continuous repulping process of OCC & LCB recycled fiber material. The recycled fiber material is brought in suspension were centrifugal and mechanical forces separate the fiber material from the unwanted materials such as metal, sand, plastic, hard to process recycled material, dirt, and polyethylene components. A hand screening process separates the unwanted material, called rejects, and the fiber material called accepts. In the laboratory process the recovered fiber material of the accept is used for handhseet making. In a commercial process

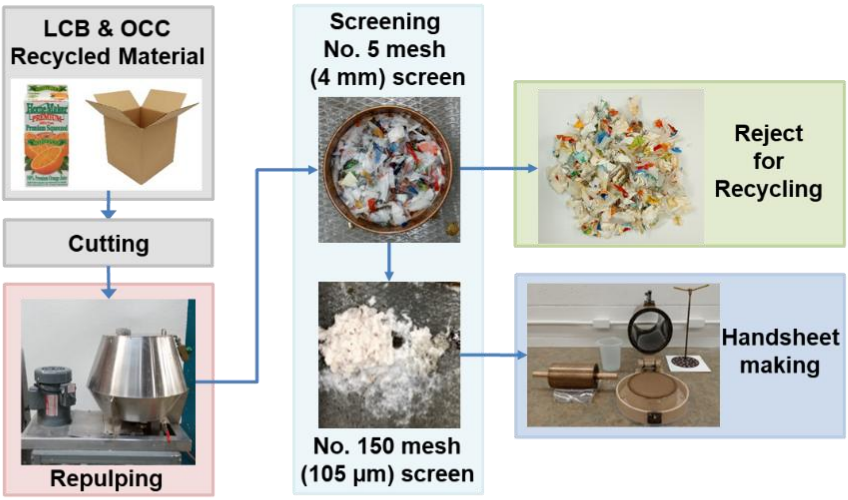



**Fig. 3. Laboratory repulping [30]**

The accept, containing the recovered fibers fiber is forwarded to the papermaking operation [31]. The recovered material is thickened and baled and then fed into recycling industries recovered material stream for the manufacture of new recycled metal and plastic materials [32].

For repulping the collected LCB and OCC material was cut with scissors it into approximately 1-to-2-inch (25 to 50 mm) pieces prior to the two repulping runs containing at 100% OCC and 100% LCB material.

10 l (2.64 gal.) of water were filled in the laboratory pulper and heated to an initial temperature of 150°F (65.6°C). Then 450.0 g of the prepared cut raw material on an Oven Dry (OD) bases were added to achieve a 4.5% Solids Content (SC). 1% Oxone addition followed based on Oven Dry (OD) fiber content. The repulping pH was adjusted to a pH of 10 using Sodium Hydroxide pellets.

Temperature and pH were measured with a portable Milwaukee MW102 pH/temperature meter as well as a Therm-Pro handheld temperature probe.

After repulping, the LCB and OCC fiber suspension in the laboratory pulper had a temperature between 140°F to 145°F (60.0°C to 62.8°C) after repulping. Each fiber suspension from the pulper and was filled in a 5-gallon (18.9 l) PVC pail and cooled down to room temperature of 68°F (20°C). The repulped LCB and OCC fiber content in the respective pails was then screened separately with a No. 5 mesh (4 mm) 200 mm diameter screen pan, and usable fiber material was collected with a large screening box lined with a No. 150 mesh (105 µm) screen. The recovered fiber material on top of the No. 150 mesh (105 µm) screen was collected in 2-gallon (7.6 l) plastic bags and stored in a cold room at a temperature of 5.0°C (41.0°F) prior to handsheet making. The fibers from the plastic bags were diluted separately and prepared according to TAPPI method T 205 sp-12 [13], before TAPPI handsheets were made.

## 2.4 Laboratory Refining

A beating or refining process increases the flexibility and bonding ability of the individual fibers by allowing the establishment of more hydrogen bonds between the individual fibers in the manufactured paper product. As a result, the strength of the produced paper product is increased [33].

Laboratory refining for the LCB and OCC handsheet development was done according to TAPPI T 200 sp-06 method [12]. A Freeness level of 400 ml CSF was selected on past experience which suggests that a fiber suspension used on a 12-inch Laboratory Fourdrinier Paper Machine run should have between 350 ml and 450 ml CSF to achieve a good run ability and sheet forming result.

Refining below the 350 ml CSF level would increase fines content and fiber shortening which would have a negative effect on paper properties.

## 2.5 Screening

Screening out usable fiber material from the individual repulping runs done, as described by Dölle et.al. (2022), by filling a portion of the repulped slurry into a No. 5 mesh (4 mm) screen pan and washing out the usable fiber material with water at a temperature of 40°C applied with a water hose [4]. Unusable material such as polyethylene, and wet strength material, etc. was retained on the screen, see Fig. 3, collected, and moved into a 4-liter plastic beaker and discarded later. The usable fiber material passing the screen was collected in a larger scree box with a 150 mesh (105 µm) screen lining. The retained fibers, see Fig. 3, in the screen box were double checked for contamination before they were moved in a 2-gallon (7.6 l) plastic bags. The collected rejects were diluted again and screened a second and third time to recover all usable fibers, which were put in the plastic bag thereafter.

## 2.6 Paper Handsheet Making

Pre-trials for handsheet making showed it was easier to produce 70 g/m² handsheets without defects as using the TAPPI test method T 205 sp-06 [13] 60 g/m² basis weight handsheets.

Prior to making handsheet with a basis weight of 70 g/m² the recovered LCB and OCC fiber material was diluted to 1.2% consistency and processed in a TAPPI style disintegrator to disperse the fibers. To prepare the handsheets, a 0.3% pulp solution was prepared and added to the handsheet forming apparatus to produce 70 g/m² handsheets for later optical and mechanical evaluation.

The produced handhseets were labeled and placed in a climate-controlled room with 50% relative humidity and a temperature of 23°C for conditioning, according to TAPPI T-402 sp-06 test method [18]. These steps were repeated for all repulping runs.

## 3. RESULTS AND DISCUSSION

### 3.1 Refining

After repulping, cooling down the repulped fiber suspension, and screening as described in section 2.4 and 2.5, half of the pulp suspension was diluted to a 0.3% consistency and the other half was diluted to a 1.57% consistency and prepared for beating according to TAPPI Testing Method T 200 sp-06, by applying TAPPI Testing Methods T 205 sp-12 and T 240 om-07 [12, 16]. Both the unrefined and refined pulp suspension were tested to determine their respective Freeness level according to TAPPI to T 227 om-09 [17].

Fig. 4., shows the freeness testing results. The unrefined OCC and LCB pulp suspension had a CSF of 651 ml and 629 ml respectively. The refined OCC suspension had a CSF of 395 ml at a 15 min beating timer, whereas the refined LCB suspension had CSF level of 405 ml at 30 min beating time, indicating that the energy needed to achieve the same freeness level is doubling in comparison not the OCC pulp.

### 3.2 Handsheet Properties

Handsheets were made from each repulping run with a target basis weight of 70 g/m² according to T 205-sp-12 [13] and tested to the in Section 2.2. listed TAPPI testing standards for mechanical and optical properties. All tests were performed in the standard conditioning and testing atmospheres according to T 402 sp-08 at a temperature of 23°C ± 1°C and a humidity of 50% ± 2% [18]. All results were in the precision statements for the referenced TAPPI and ISO methods.

Values of the measured paper properties are shown in the radar diagram Fig. 5. a, on a 0% to 100% value. The actual paper testing results are shown in Fig. 5. b as an index based on the basis weight of the paper handsheets tested, except for Porosity, Elongation, Tensile Energy Absorption (TEA), with the 0-Span paper property values is corrected to a 60 g/m² value.

#### 3.2.1 Mechanical handsheet properties

*3.2.1.1 Burst index*

The Burst Index (BI) of the manufactured handsheets is measured according to T 403 om-02 [19]. As shown in Fig. 5. a & b, handsheets made from refined OCC and LCB fiber material had approximately a 2-fold higher BI compared to handsheets made with unrefined OCC and LCB material. In addition, adding LCB fiber material increased the BI index with increasing LCB content.

*3.2.1.2 Tear index*

The Tear Index (TI) of the manufactured handsheets is measured according to T-414 om-98 [23].

Fig. 5. a & b, shows that handsheets made from refined OCC and LCB fiber material had a lower TI for the refined handsheets containing a lower amount of LCB fiber material up to a 20% LCB level. Above this level handsheets made from Refined OCC and LCB fiber material showed increased TI.

*3.2.1.3 Short compression test strength index*

The Short Compression Test Strength (SCTS) index was measured according to T 826 pm-92 [26]. The SCTS index as shown in Fig. 5. a & b, reveals that handsheet containing refined LCB fiber material had approximately a 2-fold higher SCTS index compared to handsheets made with unrefined LCB material. The SCTS index difference for the unrefined and refined OCC fiber material was only 2/3 based on the unrefined OCC material.

*3.2.1.4 Zero span*

Zero-Span (ZS) data measured with T 231 cm-07 [15] and normalized to a 60 g/m² basis weight. ZS values for for Handsheets containing refined and unrefined OCC and LCB fiber material had similar values, as shown in Fig. 5. a & b, and therefore, no significant increase of ZS values could be noticed.

*3.2.1.5 Tensile index*

Tensile strength of handsheets was meassured according to T 494 om-06 [25] and reported as Tesnile Index (TI).

As shown in Fig. 5. a & b, handsheets made from refined OCC and LCB fiber material had approximately a 2-fold higher TI compared to handsheets made with unrefined OCC and LCB material. In addition, adding LCB fiber material increased the TI index with increasing LCB content.

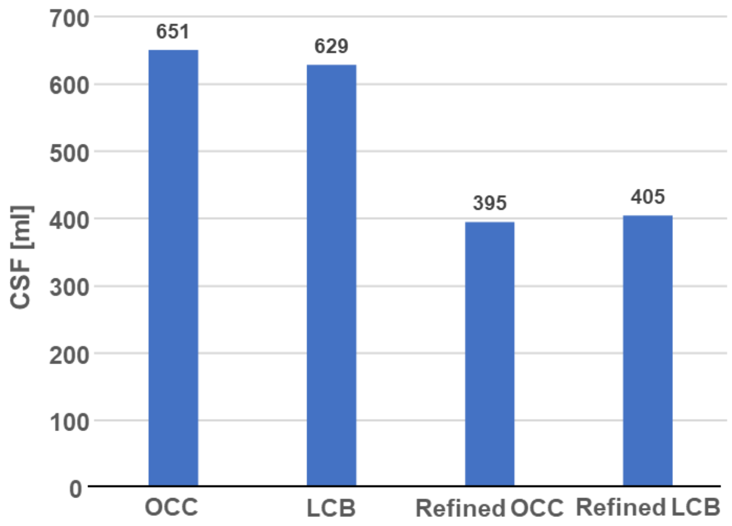



**Fig. 4. CSF level of unrefined and refined OCC and LCB fibers**

*3.2.1.6 Elongation*

Elongation of the handsheets was meassured according to T 494 om-06 [25].

Handsheets made from refined OCC and LCB fiber material had on average a 3.5-fold increase in elongation as shown in Fig. 5. a & b, compared to unrefined OCC and LCB fiber material.

*3.2.1.7 Tensile energy absorption*

Tensile Energy Absorption (TEA) was meassured according to T 494 om-06 [25]. Handsheets made from refined OCC and LCB fiber material had on average a 3.75-fold increase in TEA as shown in Fig. 5. a & b, compared to unrefined OCC and LCB fiber material.

*3.2.1.8 Porosity*

Porosity was meassured according to T 460 om-02 [24], which tests the air resistance of paper according to the Gurly method which measures the time it takes to flow 100 ml of air through paper handsheet [29]. Fig. 5. a & b, shows that handsheets made from refined OCC and LCB fiber material had a significantly lower porosity compared to handsheets made from unrefined OCC and LCB fiber material, indicating that handsheets from refined OCC and LCB material results in a more compact and better bonded handsheet.

**3.2.2 Optical handsheet properties**

Optical properties of the produced handsheets from the five repulping runs, shown in Fig. 6., were measured according to ISO standards. Color (L, a, b) and CIE Whiteness was measured according to ISO 11476 [29], Opacity was measured according to ISO 2471 [28], Brightness was measured according to ISO 2470 [27].

*3.2.2.1 Color*

Fig. 6a and Fig. 6b show the a* & b* and L* color measured for the refined and unrefined OCC and LCB pulp fiber mixtures.

As shown in Fig. 6.a, Handsheets made from OCC fiber material only had the highest a* / b* values for the refined and unrefined fiber material of (5.71/18.51) and (5.50/19.06) respectively corresponding with L* values shown in Fig. 6.b with values of 55.03% and 57.35.% for the refined and unrefined fiber material respectively.

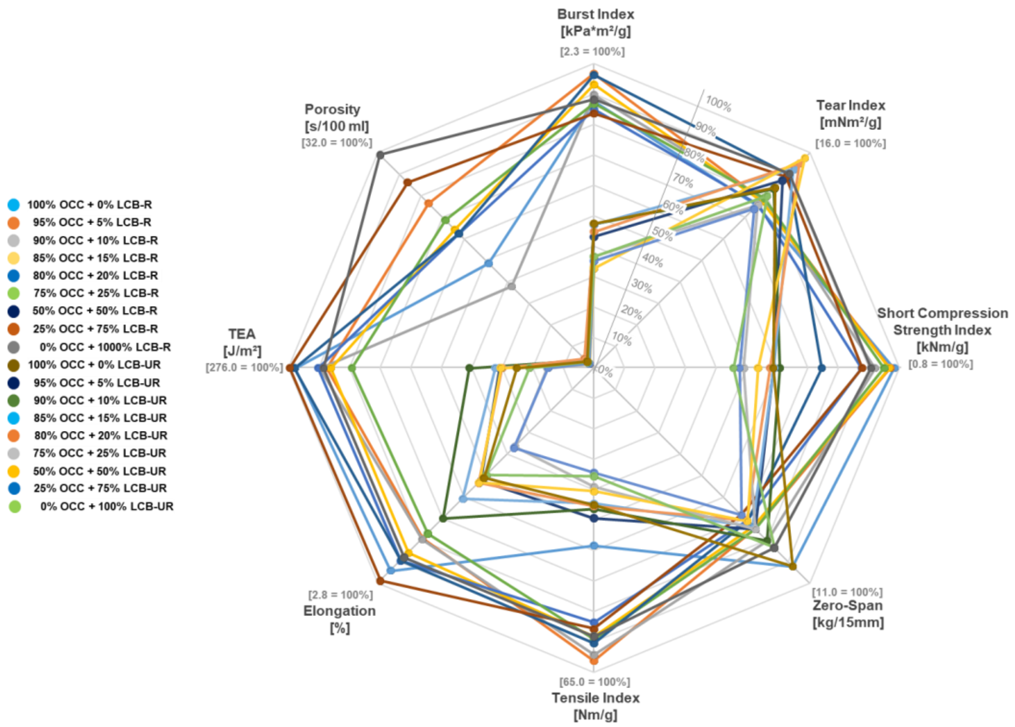
Handsheets made from LCB fiber material only as shown in Fig. 6.a, had the lowest a* / b* values for the refined and unrefined fiber material of (-0.63/1.92) and (-0.65/0.47) respectively corresponding with L* values shown in Fig. 6.b with values of 83.01% and 85.28% for the refined and unrefined fiber material respectively.

The color of the manufactured handsheets increased gradually for both the refined and unrefined OCC and LCB fiber material from a dark brow color to a lighter brown color based on increasing LCB fiber content, because of the virgin bleached softwood fibers used to manufacture the LCB paper product. Refining the OCC and LCB fiber material resulted in a lower L*, A*, and b* color value compared to the unrefined pulp.

### *3.2.2.2 Whiteness*

Whiteness values for the handsheets manufactured from OCC and LCB fiber material are shown Fig. 7., on a ±100% scale, whereas black is represented by -100% and white for +100%.

Handsheet containing OCC fiber material only, had the darkest whiteness of -108.05% and -105.50% for the refined and unrefined version respectively, whereas handsheets made only with LCB fiber material had the highest brightness of 52.27% and 64.20 % for the refined and unrefined LCB fiber material respectively. As shown in Fig. 7., an increase in LCB fiber content increased the whiteness gradually for both the refined and unrefined OCC and LCB fiber mixtures. Refining the OCC and LCB fiber material resulted in a lower brightness value compared to the unrefined pulp.




**(a)**

| | Color | Burst Index [kPa*m²/g] | Tear Index [mNm²/g] | Com. Str. Index [kNm/g] | Zero-Span [kg/15mm] | Tensile Index [Nm/g] | Elongation [%] | TEA [j/m²] | Porosity [s/100ml] |
|---|---|---|---|---|---|---|---|---|---|
| OCC 100% | | 2.02 | 12.09 | 0.79 | 10.13 | 37.84 | 2.63 | 74.32 | 15.60 |
| OCC 95%& 5% LCB | | 2.23 | 12.51 | 0.78 | 8.22 | 62.54 | 2.22 | 66.42 | 24.50 |
| OCC 90% & 10% LCB | | 2.07 | 12.58 | 0.74 | 8.82 | 61.20 | 2.23 | 68.10 | 12.20 |
| OCC 85% & 15% LCB | | 2.14 | 12.42 | 0.77 | 8.10 | 57.30 | 2.40 | 65.38 | 20.60 |
| OCC 80% & 20% LCB | | 1.96 | 12.17 | 0.70 | 7.80 | 54.32 | 2.51 | 68.68 | 20.00 |
| OCC 75% & 25% LCB | | 2.00 | 12.63 | 0.76 | 8.23 | 57.92 | 2.15 | 60.26 | 22.00 |
| OCC 50% & 50% LCB | | 2.22 | 14.40 | 0.60 | 7.82 | 58.70 | 2.50 | 74.52 | 20.00 |
| OCC 25% & 75% LCB | | 1.92 | 14.22 | 0.70 | 7.50 | 55.64 | 2.77 | 75.70 | 27.60 |
| 100% LCB | | 2.03 | 14.46 | 0.73 | 9.18 | 57.26 | 2.46 | 67.26 | 31.70 |
| OCC 100% | | 1.09 | 13.42 | 0.47 | 10.13 | 29.20 | 1.43 | 19.26 | 1.00 |
| OCC 95%& 5% LCB | | 0.99 | 13.95 | 0.47 | 8.22 | 32.00 | 1.46 | 23.36 | 1.00 |
| OCC 90% & 100% LCB | | 1.09 | 13.33 | 0.49 | 8.82 | 30.08 | 1.96 | 31.00 | 1.20 |
| OCC 85% & 15% LCB | | 1.08 | 14.80 | 0.47 | 8.10 | 28.88 | 1.70 | 24.52 | 1.00 |
| OCC 80% & 20% LCB | | 1.03 | 15.23 | 0.46 | 7.80 | 29.54 | 1.49 | 22.82 | 1.40 |
| OCC 75% & 25% LCB | | 0.84 | 12.14 | 0.39 | 8.23 | 25.26 | 1.02 | 11.66 | 0.60 |
| OCC 50% & 50% LCB | | 0.75 | 15.62 | 0.43 | 7.82 | 26.28 | 1.49 | 23.16 | 0.70 |
| OCC 25% & 75% LCB | | 0.81 | 11.85 | 0.38 | 7.50 | 22.30 | 1.04 | 11.43 | 0.70 |
| 100% LCB | | 0.84 | 12.82 | 0.37 | 9.18 | 23.08 | 1.39 | 16.04 | 0.90 |

**(b)**

**Fig. 5. Mechanical handsheet paper properties of refined and unrefined OCC and LCB fiber material, (a) graph and (b) values**

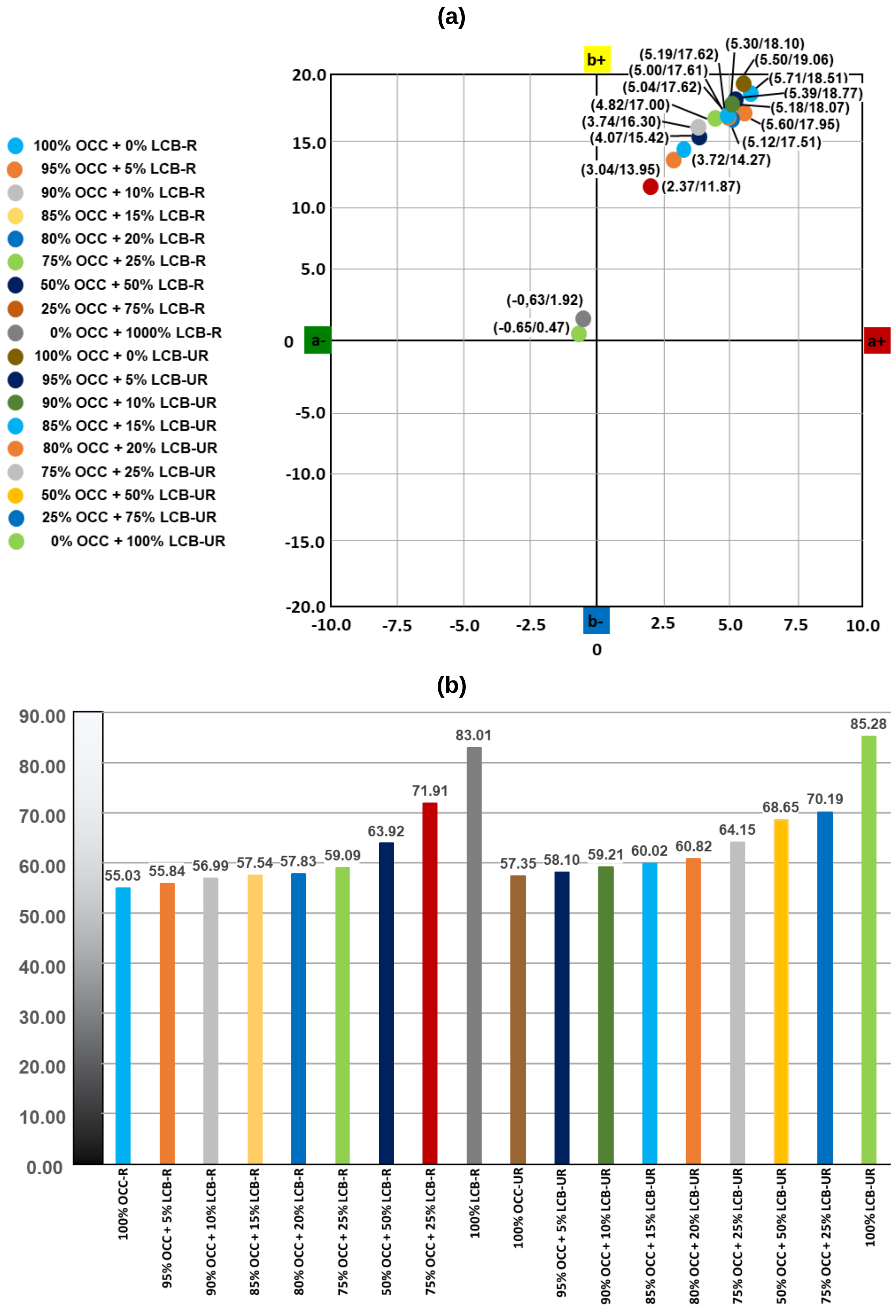



**Fig. 6. a) a* & b*, b) L* color paper properties of unrefined and refined OCC and LCB fiber material**

*3.2.2.3 Brightness*

Fig. 8. displays the resulting brightness on a 100% scale for the handsheets manufactured from OCC and LCB fiber material.

The handsheet containing OCC fiber material only, had the darkest brightness of 14.19% and 15.67% for the refined and unrefined version respectively, whereas handsheets made only with LCB fiber material had the highest brightness of 60.30% and 66.16 % for the refined and unrefined LCB fiber material respectively. As shown in Fig. 8., an increase in LCB fiber content increased the brightness gradually for both the refined and unrefined OCC and LCB fiber mixtures. Refining the OCC and LCB fiber material resulted in a lower brightness value compared to the unrefined pulp.

*3.2.2.4 Opacity*

The resulting opacity measured for the produced 70 g/m² handsheets with the different OCC and LCB fiber compositions showed a value between of 100% for all handsheets.

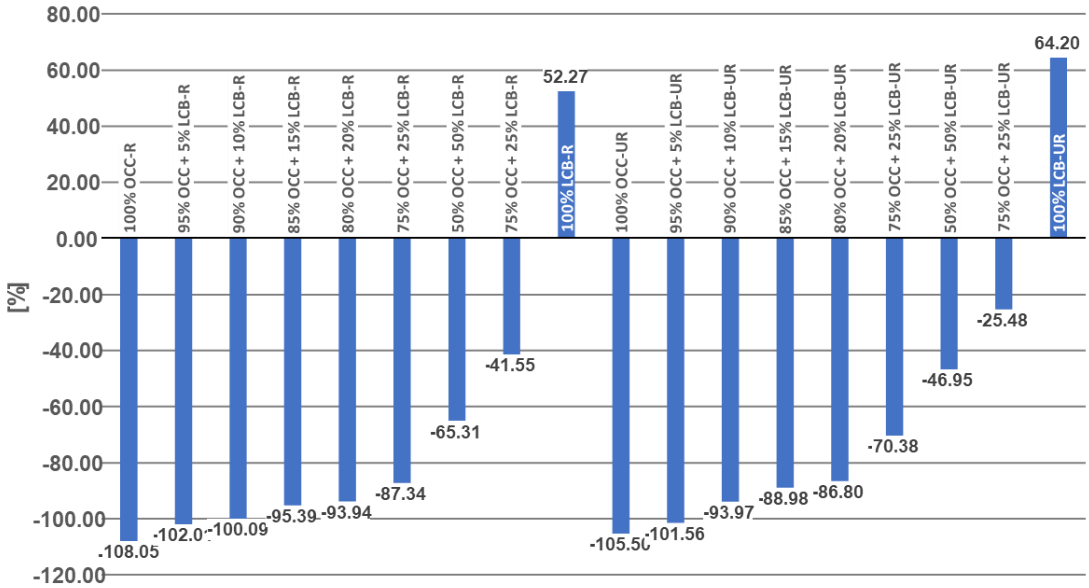



**Fig. 7. Whiteness properties of unrefined and refined OCC and LCB fiber material**

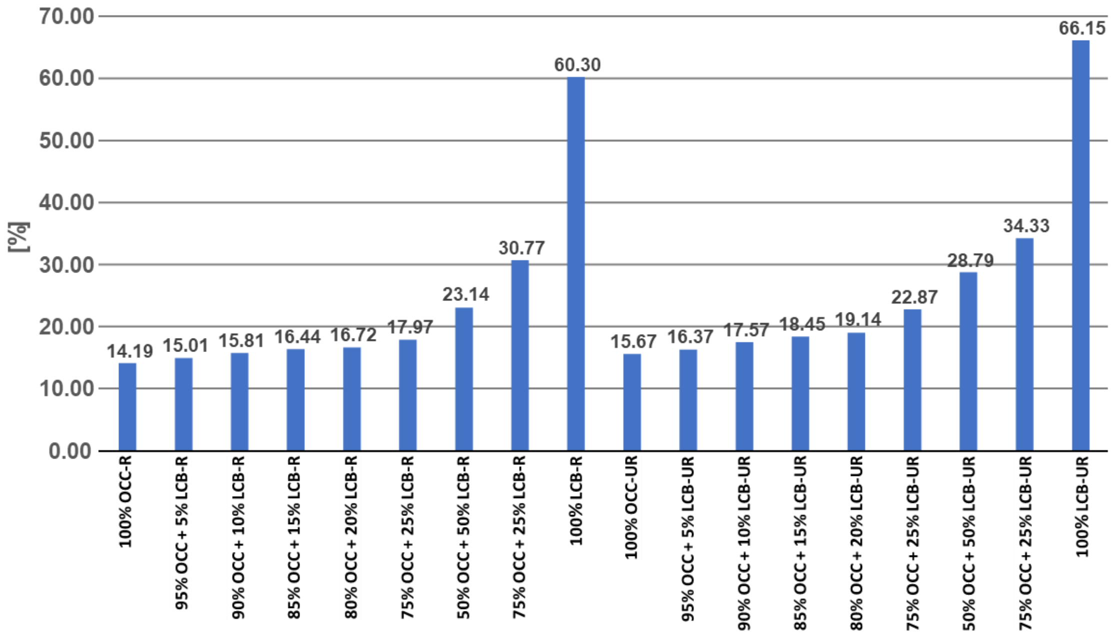



**Fig. 8. Brightness Properties of unrefined and refined OCC and LCB fiber Material**

## 4. CONCLUSION

Packaging materials for packaging liquid goods may contain over 75% virgin bleached fiber material that can be used to offset and or upgrade existing board products.

In this laboratory handsheet study, investigated the use of recycled LCB materials which are currently not utilized from the recycling stream for paper board production.

All tests conducted were done according to TAPPI and ISO testing standards.

OCC and LCB recycled fiber material was repulped for 30 minutes at a pH of 10, a temperature of 150°F (65.6°C), and 1% Oxone addition based on fiber content under laboratory conditions.

Handsheets made from repulped material containing OCC fiber material showed an up to 3-fold higher mechanical paper properties if refined OCC and LCB fiber material is utilized for BI, TI, SCTS, TEA and Elongation. Tear Index values and 0-Span values were comparable, whereas porosity decreased with refining the OCC and LCB fiber material.

Handsheets made from refined OCC and LCB fiber material had approximately a 2-fold higher TI compared to handsheets made with unrefined OCC and LCB material. In addition, adding LCB fiber material increased the TI index with increasing LCB content.

Color values L*, a*, and b* of the manufactured handsheets increased gradually for both the refined and unrefined OCC and LCB fiber material from a dark brown color to a lighter brown color based on increasing LCB fiber content. Refined OCC and LCB fibers resulted in a slightly darker color value. This is due to the virgin bleached softwood fibers used to manufacture the LCB paper product.

Increased LCB fiber content is increasing the brightness of the manufactured handsheet from OCC only containing handsheets with 14.19% and 15.67% gradually to 60.30% and 66.16% for the refined and unrefined fiber addition respectively.

Opacity measured of this study showed a 100% value for all manufactured handsheets.

Recycled LCB fibers can be used as a valuable source of recycled fiber material with the potential to upgrade board paper products regarding mechanical and optical requirements. The highest benefits are in the addition range up to 25%. Additional benefits might foster increased sustainability, biodegradability, and eco-efficiency of the paper board product.

However, more research is needed to assess the optimum LCB fiber addition for board paper products including processing condition, and paper manufacturing conditions, including economic benefits as the LCB fiber material is applied.in regard to improvement of mechanical and optical properties the resulting board paper product.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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