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A Study on Laboratory Type Paper Machine Using Nano Fibrillated Cellulose from Recycled Old Corrugated Containerboard as Bio Additive in Board Production

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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

Raw material, energy, water, and additive cost are challenges for today's board manufacturing and new sustainable solutions are needed to produce paper products with an favorable environmental footprint.
A laboratory Fourdrinier paper machine study manufactured a board product with a targeted basis weight of 80 g/m² without and with the addition of ground calcium carbonate at a targeted filler level of 10%. Nano fibrillated cellulose produced from recycled old corrugated containerboard with a Valley Beater at a Canadian Standard Freeness level of 40 ml was added at 4% based on oven dry

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basis weight. Results revealed an increased ash and fine retention as well as an increased burst Index, short span compression strength, and tear index for the base paper as well as with and without ground calcium carbonate addition.

Keywords: Beating; bio additive; Cellulose Nano fibrillated; old corrugated container board; paper; papermaking; refining.

1. INTRODUCTION

Challenges for paper manufacturer today are rising raw material, energy, water, and additive cost. Imposed environmental regulation and consumers demand for environmentally friendly products increase production cost for paper and board products. All this, demands new solution of utilizing raw materials, improve production processes, reduce energy consumption, and lower CO_2 footprint of the produced products, leading to a leaner, sustainable paper product with increased biodegradability and eco-efficiency and favorable environmental footprint [1,2,3].

Board and packaging product production and consumption have steadily increased in the past. Internet sales during pandemic years in 2020 and 2021 resulted in a high demand of board and packaging products, requiring board and packaging producers to increase their production capacities [4].

The use of recycled fiber materials does not need a chemical pulping process [5], and bio-based additives manufactured from recycled fiber materials such as Nano Fibrillated Cellulose (NFC) from Old Corrugated Containerboard (OCC) can both help to achieve a more favorable environmental footprint.

Nanocellulose (NC) is a general term that includes natural cellulosic nanomaterials, both from NFC and Cellulose Nanocrystals (CNC). NFC are manufactured by a mechanical process called beating or refining, high pressure homogenization, enzymatic hydrolysis, ultrasonication and steam explosion, cryo-crushing, and hydrolyzation process [6].

The application of NC is large and includes thermal insulation applications, barrier coatings, optical applications in thin film applications, 3-D printing, application as catalyst carrier for metals, biomedical applications, and a variety of paper applications as strength enhancing additive and including manufacturer of transparent paper and films [6,7].

However, despite the promising application potential of NC materials drawbacks compared to established plastic or chemical-based materials are economic and environmental challenges due to energy needed, chemicals used, and additional processes needed in an paper manufacturing operation. Hashemzehi et. al reports cost of \$7 to \$12 per kilogram of NC produced [6]. At present time NC material are produced on pilot scale and cost of small amounts are over 10 to 20-fold of the previous mentioned numbers based on NC characteristics.

Each paper manufacturing process has a beating/refining process installed before the fiber suspension enters the wet end of the paper manufacturing process. Refining/beating helps to improve the fiber materials bonding and dewatering ability for the paper manufacturing process. The refined fibers are then able to form a strong and smooth paper sheet with the desired properties during the paper manufacturing process [8,9]. Therefore, preparing NFC fiber material with conventional beating/refining process is logical, because paper manufacturing installation have these processes already installed and are familiar with the operational conditions.

The following research project investigates the addition of NFC produced from OCC fiber material applied on a 12” pilot paper machine board paper production run.

2. MATERIALS AND METHODS

The following materials and methods were used for the study of applying NFC manufactured from OCC.

2.1 Materials Used

OCC material was obtained from the stock preparation and wet end of a board paper mill in New York State. Papermaking Ground Calcium Carbonate (GCC) was obtained from industrial supplier in the United States.

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. Performed tests were in the precision of the used testing standard.

Beating of pulp (Valley beater method) in accordance with T 200 sp-06 "Laboratory beating of pulp (Valley beater method)" [10]. Physical testing of handsheets was performed in accordance to T 220 sp-06, "Physical testing of pulp handsheets" [11]. Freeness of pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09 "Freeness of pulp (Canadian standard method)" [12]. Consistency of a pulp suspension was measured with TAPPI T240 om-07 "Consistency (concentration) of pulp suspensions" [13]. Fines content was determined with a Britt Jar testing device according to TAPPI T261 cm-00, "Fines fraction by weight of paper stock by wet screening" [14]. 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" [15]. Burst Index was measured in accordance with T 403 om-02 :Bursting strength of paper" [16]. Basis weight was measured with T 410 om-08. "Grammage of Paper and Paperboard (weight per unit area)" [17]. Moisture content of pulp was determined by T412 om-06 "Moisture in pulp, paper and paperboard" [18]. Tear resistance was measured according to T 414 om-04 "Internal tearing resistance of paper (Elmendorf-type method)" [19].

Short span compressive strength was measured according to T 826 pm-92 "Short span compression strength of containerboard" [20].

2.3 Pulp Beating Methods

Beating of the OCC pulp suspension for the production of the NFC was done using a laboratory Valley Beater shown in Fig. 1. according to TAPPI test method T200 sp-06 [10].

Beating occurs as interaction of the stator bed plate assembly (5) consisting of beater bar (3) and beater bar spacers (4) as it is pressed with force F against the turning rotor (1) with beating blades (2). During the interaction between rotor and stator pulp fibers are collected on the leading edges of the rotor and stator bars (Fig. 2. a). An edge to surface treatment of the fiber material is initiated as the leading edge of the rotor bar approaches the leading edge of the stator (Fig. 2.b). Refining is performed during this surface-to-surface stage, shown in Fig. 2.c), when the bar edges initiate mechanical treatment and friction between fibers. The refining stage continues until the leading edges reach the tailing edges of the opposite bars. The fibers are then released into the grove of the filling during the release stage shown in (Fig. 2.d) [21].

Fig. 1. Valley Beater [21]

For the production of NFC from OCC material a beating curve shown in Fig. 2. was developed. The initial CSF was 560 ml at the start and 392 ml after 190 minutes of beating. The lowest CSF was 20 ml after 120 minutes of beating. Based on the OCC beating curve NFC was produced at a CSF level of 40 at a refining time of 140 minutes.

2.4 Laboratory Fourdrinier Paper Machine Run

For upscaling the laboratory straw art paper handsheets into a continuous production scale a 12-inch (304 mm) wide Laboratory Fourdrinier Paper Machine (LFPM) located at the pilot plant of the Chemical Engineering Department at SUNY-ESF is used. The description of the paper production system set up is described by Dölle & Rainville [22].

2.4.1 Preparation of OCC material

OCC disk filter pulp was prepared with the stock preparation system arrangement shown in Fig. 2.

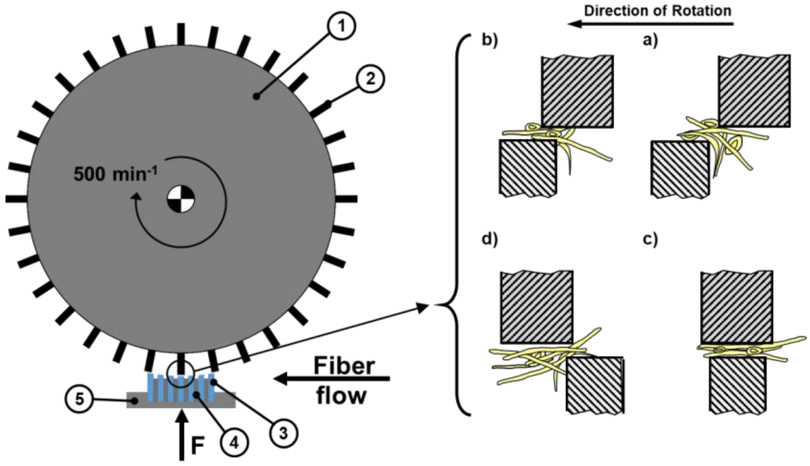

Fig. 2(I). Valley Beater principle and rotor stator beating interaction, 1) Beater roll, 2) Beater blade, 3) Bed plate beater bars, 4) Bed plate beater bar spacer, 5) Bed plate assembly [21]

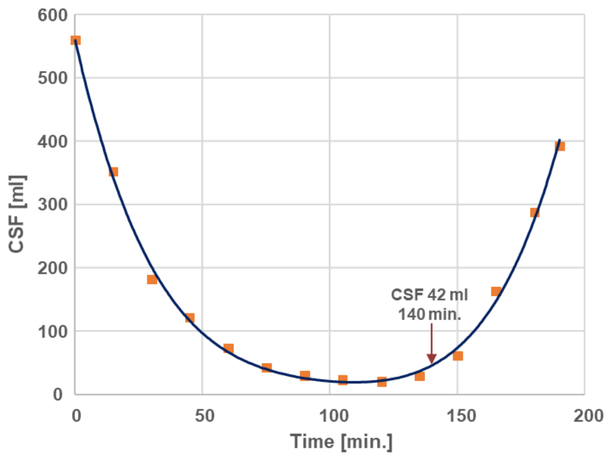

Fig. 2(ii). Refining curve of OCC pulp

A total of 20.0 lbs. (9.0 kg) OD OCC disk filter pulp was disintegrated in the 35 gal (132.5 l) low consistency laboratory pulper for 3 minutes at 20°C in five batches at 5% consistency using 10.0 lbs. (4.54 kg) of the REC material and 22.8 gal (86.26 l) of water.

After each disintegration batch the 5% REC suspension was pumped with a 3 hp (2.24 kW) transfer pump into two 240 gal. (908.5 l) storage chests, that is agitated each with a 1.5 hp (1.12 kW) propeller agitator. After pulping the 5% OCC suspension in the storage chests was diluted to a refining suspension of 3 % by adding 31.9 gal. (121.0 l) of water. The 79.9 gal (302.6 l) of OCC pulp suspension in the storage chests was refined to a CSF of 440 ml with a the 10 hp (7.46 kW) low consistency conical Jordan refiner. Approximately 26.7 gal (100.8 l) of the refined OCC pulp suspension were pumped into storage chest 2 to be used for the initial OCC based trial. To the remaining pulp suspension in storage chest 1, 241 g OD of NFC OCC with a CSF value of 40 ml, prepared as described under Section 2.5, was added to the storage chest at a consistency of 1.57%. The resulted pulp suspension in storage chest 1 and 2 was diluted to a machine chest consistency of 1.5% by adding 49.4 gal (187.1 l) and 26.7 gal (100.8 l) respectively of water at 20°C to the pulp suspensions. This resulted in 110.8 gal (419.6 l) and 53.2 gal (201.6 l) of OCC pulp suspension respectively in the storage chests available for paper production.

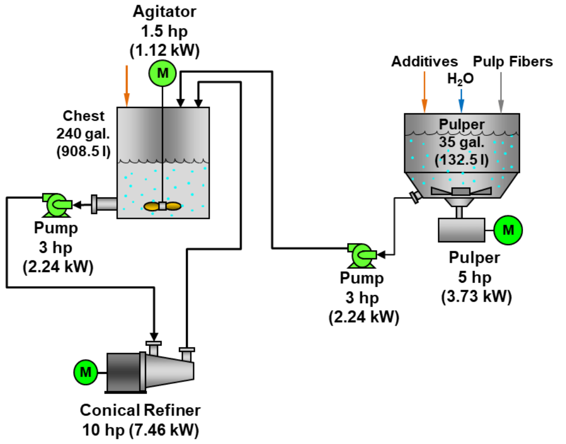

Fig. 3. Laboratory stock preparation system [11]

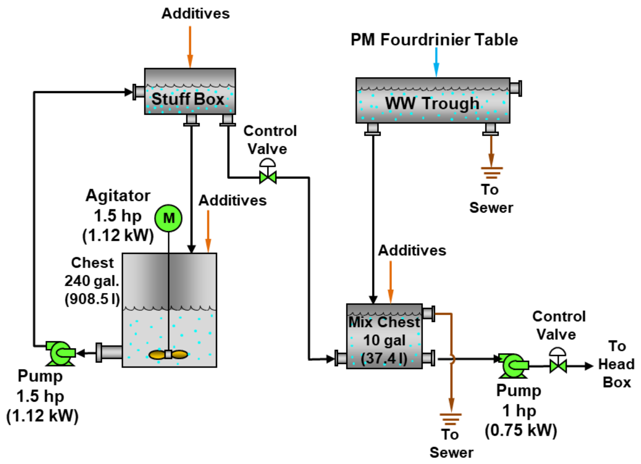

Fig. 4. Wet End of the 12" laboratory Fourdrinier paper machine [11]

2.4.2 12-inch laboratory fourdrinier paper machine run

For the production of the OCC paper product without and with NFC OCC pulp a 12-inch Laboratory Fourdrinier Paper Machine (LFPM) system was used without adding additional wet-end chemicals. The LFPM wet end system, and the LFPM itself is shown on Figs. 4 and 5 respectively.

After all preparations were made, the final production run of the LFPM paper machine was executed and the respective pulp suspension was pumped from the storage chest into the machine chest of the LFPM and diluted to approximately 1.2%. The fiber flow to the headbox of the LFPM at a consistency of 1% was set at approximately 1.40 gal/min (5.29 l/min) to achieve the desired basis weight of 80 g/m² for the board paper product. The 70 inch (1778 mm) long Fourdrinier section vacuum levels were set at 0 for the 1st, 27579 Pa for the second vacuum section, 0 for the 3rd to 6th, 13789 Pa for the 7th, 27579 Pa for the 8th, 48263 Pa for the 9th, and 0 for the 10th vacuum section. The 1st and 2nd press was operated at 26 psi (179.264 kPa) and 40 psi (275,790 kPa) respectively. The Yankee-Dryer (J1) was operated at 162.7°C (325°F). Dryers (D1-D6) were heated at 168.3°C (335°F). Dryers (D7 & D8) were not heated. Dryers (D9 & D10) were operated at 171.1°C (340°F). Dryers (D11-D18) was kept at 176.6°C (350°F). The calendar section was operated without pressure and heat. After the calendaring section the board paper was rolled up and the paper rolls were conditioned according to TAPPI Test method T402 [15] before cut in size for testing.

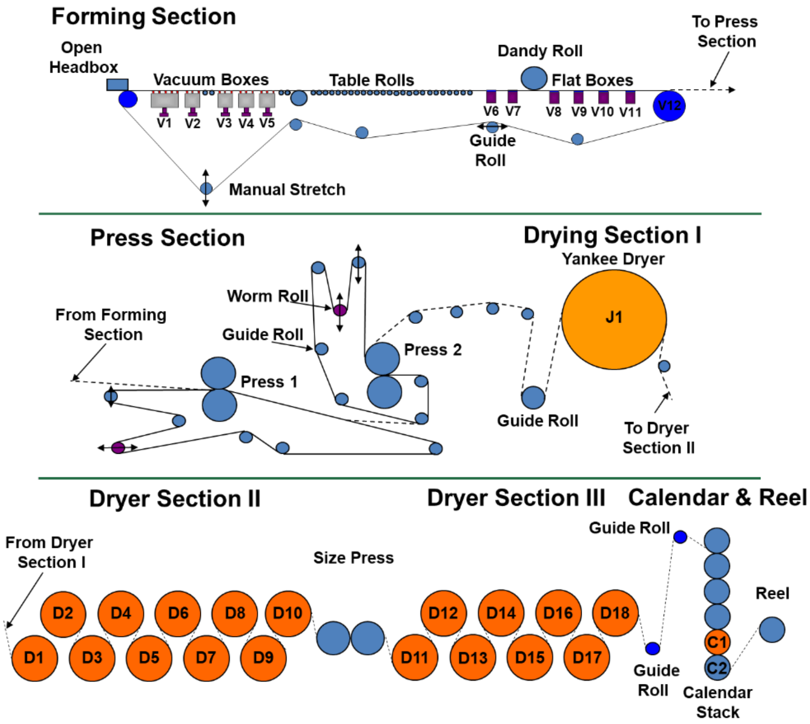

Fig. 5. Laboratory Fourdrinier paper machine [11]

3. RESULTS AND DISCUSSION

The LFPM run material preparation was executed as described in Section 2 with a targeted Basis weight of 80 g/m², and consisted of five runs including: OCC only, OCC and NFC-HR (OCC+HR), OCC and GCC (OCC+GCC), and GCC (OCC+HR+GCC). The targeted ash content was 10% for the GCC addition.

Paper testing during the LFPM run was conducted immediately following the paper product reaching the reel at a temperature of 23°C and a relative humidity of 30%.

Lab testing of the produced board paper with and without NFC was conducted after the selected paper specimens were conditioned for several days at a temperature of 23°C and a relative humidity of 50% according to T402 [15].

3.1 Fines Content

A fines retention study, shown in Fig. 6, using a Britt Jar testing device according to TAPPI T261 cm-00 [14] was used to evaluate OCC pulp suspension to the headbox (OCC PMHB) of a commercial paper machine OCC pulp suspension to the headbox of the LFPM (OCC LFPM).

The commercial OCC PMHB sample had a fine content of 56.54%, the White-Water OCC WW a fines content of 99.85%, and the NFC high refined pulp (OCC PM+HR) added to the OCC PMHB pulp suspension in the laboratory at 4% solids content based on the OCC PMHB oven dry (OD) solids content had 3.45% lower a fines content at 53.09%.

The OCC pulp collected from a commercial disk filter and prepared for the LFPM run as described in Section 2.5.1 and refined to a CSF level of 440 ml had a fine content supplied to the LFPM headbox (OCC LFPM) of 75.76%. The pulp suspension to the LFPM headbox with NFC HR added to the OCC LFPM pulp suspension at 4% solids content based on the OD solids content had a 28.56% lower fines content at 47.20%. Adding GCC to the pulp suspension without and with NFC HR achieved a fines content of 28.5% and 34.4% respectively, which is 8.70% lower for the GCC addition and 12.80% lover for the GCC and NFC HR addition. Addition of NFC-HR resulted in a lower fine content of 4.10% compared to GCC addition without NFC-HR. Addition of NFC-HR at a 4% level lowers the fine content in the suspension to the headbox and serves as a fine collecting agent.

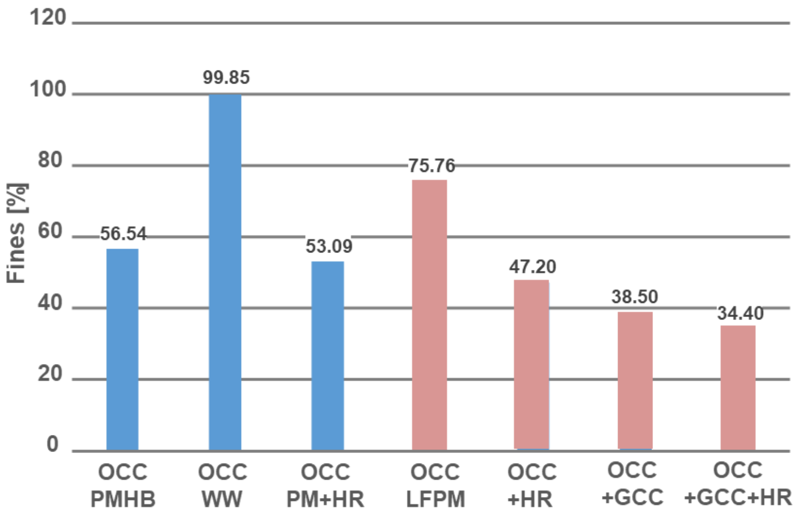

Fig. 6. Fines content based on Britt Jar test

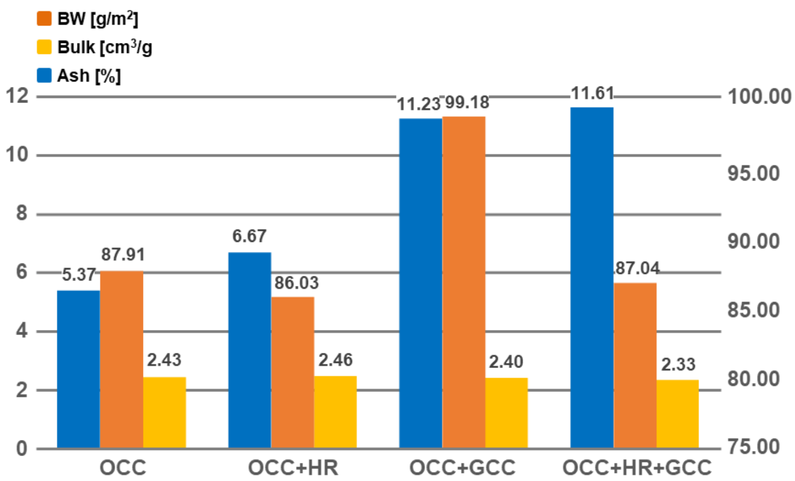

Fig. 7. Basis weight, bulk and ash content

Fig. 7 shows that for the LFPM runs OCC only, OCC+HR, OCC+GCC, and OCC+HR+GCC the BW and ash content was 87.91 g/m² at 5.37%, 86.06 g/m² at 6.67%, 99.18 g/m² at 11.23%, and 87.04 g/m² at 11.61% respectively. Bulk achieved was between 2.43 cm³/g and 2.33 cm³/g for the four runs. Adding 4% HR pulp increased ash content for the OCC and GCC version of 1.37% and 0.38%. Increased ash retention can be translated into reduced drying energy and or increased production [23].

The Burst Index (BI) based on BW is shown in Fig. 8 for the LFPM run. The BI was 0.82 kPa*m²/g for OCC only at a BW of 81.73 g, 0.94 kPa*m²/g for OCC+HR at a BW of 86.03 g, 0.78 kPa*m²/g OCC+GCC at a BW of 99.18 g, and 0.89 kPa*m²/g OCC+HR+GCC at a BW of 87.04 g. Adding 4% HR pulp increased the BI for the OCC and GCC version of 0.14 kPa*m²/g and 0.11 kPa*m²/g respectively, which can be translated in the production of a stronger board paper product with and without GCC filler material based on the OCC base paper.

STIFFI Index for the LFPM run in Machine Direction (MD) and Cross Machine Direction (CD) is shown in Fig. 9 in comparison to the BW. OCC only had 0.78 kNm/g for MD and 0.41 kNm/g for CD at a BW of 87.91 g. OCC+HR showed 0.73 kNm/g for MD and 0.44 kNm/g for CD at a BW of 86.03 g. OCC+GCC resulted in 0.62 kNm/g for MD and 0.41 kNm/g for CD at a BW of 99.18 g, and OCC+HR+GCC had 0.66 kNm/g for MD and 0.40 kNm/g for CD at a BW of 87.04 g. Adding 4% HR pulp decreased the MD

STIFFI Index for the OCC version of 0.05 kPa*m²/g. the GCC version showed and increased MD STIFFI Index of 0.04 kPa*m²/g respectively. The CD STIFFI Index showed similar values between 0.41 and 0.44 kPa*m²/g. Adding HR pulp showed a potential improvement if the board product contains additional GCC filler material.

Tear Index (TI) in Machine Direction (MD) and Cross Machine Direction (CD) in comparison to the BW for the LFPM runs is shown in Fig. 9. OCC only had 11.04 mNm²/g for MD and 10.97 mNm²/g for CD at a BW of 87.91 g. OCC+HR showed 12.28 mNm²/g for MD and 10.38 mNm²/g at a BW of 86.03 g. OCC+GCC resulted in 8.99 mNm²/g for MD and 8.22 for CD at a BW of 99.18 g, and OCC+HR+GCC had 10.51 mNm²/g for MD and 9.39 mNm²/g for CD at a BW of 87.04 g. Adding 4% HR pulp increased the MD TI for the OCC version of 1.24 mNm²/g and decreased the CD TI by 0.61 mNm²/g. For the GCC version the MD and CD TI increased by 1.52 mNm²/g and 1.17 mNm²/g respectively. Adding HR pulp showed an potential improvement for the board product without and with GCC filler material.

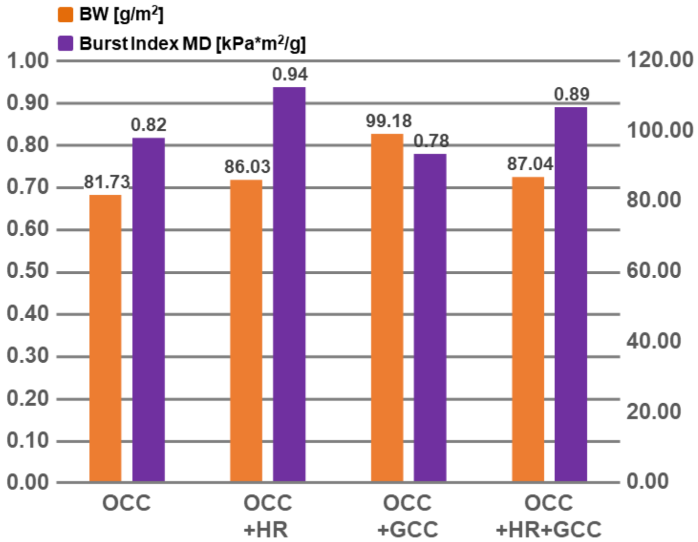

Fig. 8. Burst Index based on basis weight

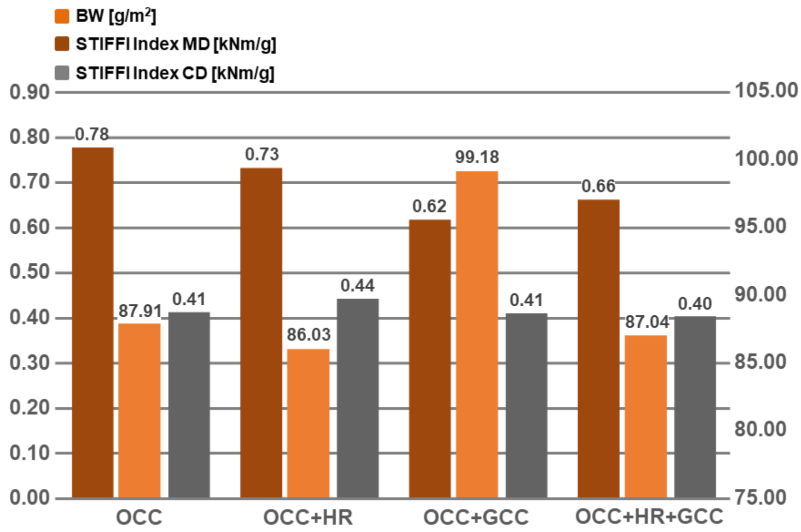

Fig. 9. STIFFI Index MD & CD based on Basis Weight

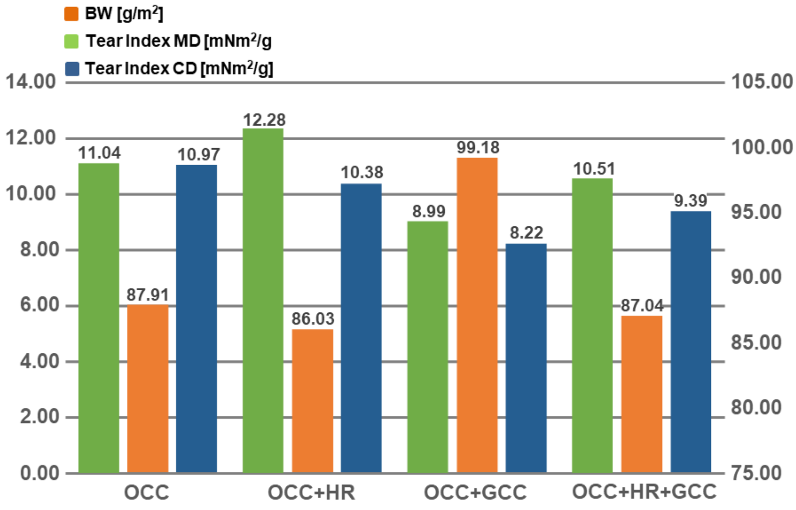

Fig. 10. Tear Index MD & CD based on Basis Weight

4. CONCLUSION

A laboratory Fourdrinier paper machine study showed that an addition of 4% nano fibrillated cellulose from recycled old corrugated containerboard based on oven dry fiber content revealed increased ash and fine retention as well as an increased burst Index, short span compression strength, and tear index for the base paper with and without ground calcium carbonate addition.

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COMPETING INTERESTS

Author has declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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