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Improvement of Fiber Fines Retention and Mechanical Properties of Board Paper Using Corn and Tapioca Starch- A Handsheet Study

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Authors' contributions

This work was carried out in collaboration among all authors. Author KD supervised and managed the study, wrote the final draft and approved the final manuscript.

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ABSTRACT

Steadily increasing production cost in the paper industry require more efficient resource allocation and utilization of recycled materials and the use of renewable materials and additives to become more environmentally friendly. With this project, 100 g/m² TAPPI handsheets from industrial processed OCC fiber material were produced, without starch and starch in cooked and uncooked form, air-dried at 23°C and contact-dried at 120°C. Starch addition levels were 6.0, 18.0 and 24.0 kg/mt (12.0, 36.0, and 48.0 lbs./st) for pearl and cationic starch, and 2.0, 6.0 and 8.0 kg/mt (4.0, 12.0, and 16.0 lbs./st) for tapioca starch. Fines were measured with a Britt Jar devise having a 75 µm (200 mesh) screen. The highest tensile index improvement of 35.71% for uncooked tapioca starch at an addition rate of 16 lbs./st. The highest tear index improvement of 1.86% was for pearl starch at an addition rate of 12 lbs./st for the cooked & contact dried application. The highest burst index improvement of the produced handsheets was for uncooked & contact dried cationic starch at an addition rate of 12 lbs./st with an improvement of 21.49%. Application of pearl starch showed the largest difference in fines content at the 12 lbs./st and 48 lbs./st of fiber concentrations,

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reducing the fines content by 22.2% and 24.7% based on solids content respectively. Pearl starch outperformed cationic and tapioca starch products and showed the highest potential for fiber savings and net profit value.

Keywords: Fines retention; mechanical paper properties; OCC; corn starch; tapioca starch; retention.

1. INTRODUCTION

Efficient resource allocation is becoming increasingly necessary to conscientiously reach sustainable practices for economic reasons. The paper industry proves to prominently exemplify this principle by applying recycled paper materials for reuse of fibers into their paper and board products which improves the environmental foot print of the industry [1,2].

Steadily increasing production cost and environmental regulations for paper and board products and their application demand new solution of utilizing raw materials and chemicals for the production process [3,4]. To become more environmentally friendly the paper industry sector is increasing its efforts to become more sustainable, biodegradable and eco-efficient by implementing the use of renewable materials and additives, which can replace less environmentally friendly additives in the future [3,4].

It is known that paper production utilizing recycled fiber for their furnish produce 2-4 times as much sludge than mills processing virgin fibers for paper production [5]. Mill sludge is largely composed of fiber materials know as fines [6]. Fines are characterized as fiber materials below the 200 mesh (mm) screen size [7].

Starch is a common and crucial bio-based additive in the papermaking and conversion process [8], and is known as one of the earliest sizing and dry strength additives and has been used in papermaking as early as 768 A.D. to improve paper surface properties for the application of ink [9]. Starch is also known as “beater starch”, because it was often added to the fibers in the beater. Starch as dry strength additives can be added at many locations in the papermaking process [10].

Starches as naturally occurring polymers commonly used in the paper industry as dry strength agents, coating binders, retention aids in wet end applications to minimize fiber loss, and as adhesives in converting operations. In addition, starch products provide additional strength to the paper sheet [11,12,13]. In addition, starches can be modified to improve their functional properties in the laboratory leading to thermoplastic and cationic starches [14].

Behind biomass fibers and fillers, starch is the third leading component by weight in paper [11,15]. Starch is considered a low-cost and sustainable product, as it is naturally abundant and biodegradable [16]. In addition, starch provides impressive strength and surface benefits to a variety of different paper grades, including packaging paper and cardboard grades [17].

Starch is a polymeric chain of glucopyranose units and naturally contains a combination of two types of polymers: One branched and the other linear. To separate the two types of starch polymers a fraction process is necessary. Amylose is the linear starch polymer and accounts for 27% of starch. Amylopectin is the branched polymer and accounts for the remaining 73% of starch. Cooking starch in liquid, commonly water, is necessary to promote the penetration of water into the granules, swelling them up in a process referred to as gelatinization. Starch is insoluble in cold water. The thermomechanical cooking process solubilizes starch in water, decreases the viscosity of the solution, and decreases the molecular weight of starch [18].

Today in the industrial process of papermaking, starch plays a variety of different roles, where it can gel, thicken, and form to create optimal sheet construction [19]. Given that, starches require time to bond with fibers and consideration must be taken to add them prior to formation of the paper sheet [4]. Due to starch’s substantial use in the paper industry, there is a variety of different products on the market, with major sources ranging from corn and potato to waxy maize, wheat and tapioca [20,13].

Starch applied at the wet-end mixing systems can range from modified to cationic, anionic or amphoteric cationic or amphoteric pending on the paper product produced [11,21].

Today, uncharged and unmodified pearl starch is a widely utilized additive to the pulp and paper industry, specifically as a binder agent in multiple sheet forming and as laminate in corrugated board processes [22,23] to increase inter-fiber bonding by cross-links with the fibers within the sheet [22]. Once the starch bonds with the fibers it can increase and improve formation, influence efficiency in draining on the machine and bind sheets in the corrugation process [17]. Unmodified starch often has limitations, because it is high solids and high viscosity, requiring increased water usage and costly preparation systems and processes [24].

Studies comparing different types of starches have found that cationic starches perform better than native starches in tensile, tear, and burst [19]. Cationic starches provide several benefits on the wet-end of the machine including increased fiber and ash retention; improved process run ability, better dewatering behavior, and cost-effectiveness compared too unmodified starches [16]. Cationic starch is also preferred on the dry-end because the positive charge that is introduced on the chain forms an electrostatic bond with the negative cellulosic fibers of the biomass [23]. In addition, these modified starches coat the fillers and fiber to create better retention of chemistries within the paper, which promotes better paper performance and cost savings [25].

Paper production is a tailor made process for the individual paper grades produced. Fiber materials and additives are added based on paper properties required for the finished product. Increasing use of recycled materials require adoption of already implemented recipes to minimize fiber losses through fines. This study is looking to evaluate the impact of fines absorption into the paper sheet using recycled Old Corrugated Container (OCC) material as fiber source. The wet-end applications of unmodified pearl starch, cationic starch, and unmodified tapioca starch and their potential mechanical paper strength and economic are tested by preparing handsheets with varying additions of unmodified and cationic corn starch and tapioca starch.

2. MATERIALS AND METHODS

2.1 Pulp Fiber Materials

Pulp fibers from a paper mill using OCC material was collected at the headbox of the paper machine and sent to the College of Environmental Science and forestry (ESF), Department of Chemical Engineering (CHE) in Syracuse, New York.

2.2 Starch Make Down

The wet-end additions tested in this study were pearl starch, cationic starch, and tapioca starch. Pearl starch is a dent unmodified corn starch and provides the lowest cost barrier for the papermaker. Cationic starch is a modified starch with a positive charge, giving it additional bonding propensity to negatively charges fibers during stock preparation. Tapioca starch is a relatively expensive starch and is less commonly used in the paper industry [26].

The starch solutions were prepared as described below and then added to the fiber suspension based on handsheet oven Dry (OD) weight.

2.2.1 Unmodified and cationic corn starch

Uncharged unmodified and cationic cornstarch was prepared as described by Doelle et.al. [27]. Under constant stirring, 9 g of Starch powder was added to a 500 ml beaker containing 291 ml of distilled water at a temperature of 20°C (68°F) to reach a solid content of 3%. The beaker containing the starch solution was covered with an aluminum foil, and the starch solution was then cooked for 30 min at 95°C - 98°C (68°F) under constant stirring using a Fischer Scientific stirring hot plate. After cooking, the solution was stored in a refrigerator at 4°C. Prior to applying the starch solution to the pulp fiber solution, the starch was heated to 30°C.

2.2.2 Tapioca starch

Tapioca starch was prepared as described by Doelle et al. [14]. Under constant stirring, 9 g of Starch powder was added to a 500 ml beaker containing 291 ml of distilled water at a temperature of 20°C (68°F) to reach a solid content of 3%. The beaker containing the starch solution was covered with an aluminum foil, and the starch solution was then heated to 48.9°C (129°F) and kept at the temperature for 30 min under constant stirring using a Fischer Scientific stirring hot plate. After cooking, the solution was stored in a refrigerator at 4°C. Prior to applying the starch solution to the pulp fiber solution, the starch was heated to 30°C.

2.3 Testing Methods

Handsheets were prepared according to TAPPI T205 sp-12, “Forming handsheets for physical tests of pulp" [28]. Ash content was analyzed by TAPPI T211 om-02, "Ash in wood, pulp, paper and paperboard: Combustion at 525°C" [29]. Physical testing of handsheets was carried out with TAPPI T220 sp10, "Physical testing of pulp handsheets" [30]. Freeness was observed following TAPPI T227 om-09, "Freeness of pulp (Canadian standard method)" [31]. Papermill headbox sample consistency was determined with TAPPI T240 om-07, "Consistency (concentration) of pulp suspensions" [32]. 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" [33]. All prepared paper handsheets were subject to standard atmospheric conditions according to TAPPI T402 sp-13, "Standard conditioning and testing atmospheres for paper, board, pulp handsheets" [34]. Burst strength indexes were prepared in accordance with TAPPI T403 om-02, "Bursting strength of paper" [35]. Grammage was evaluated with TAPPI T410 om-08, "Grammage of Paper and Paperboard (weight per unit area)" [36]. Thickness values were measured with TAPPI T411 om-10, "Thickness (caliper) of paper, paperboard, and combined board" [37]. Moisture contents were analyzed according to TAPPI T412 om-06, "Moisture in pulp, paper and paperboard" [38]. Tear strength was determined by TAPPI T414 om-12, "Internal tearing resistance of paper (Elmendorf-type method)" [39]. Paper opacity values were recorded according to TAPPI T425 om-06, "Opacity of paper (15/d geometry, illuminant A/2°, 89% reflectance" [40]. Tensile strength index was calculated and measured by TAPPI T494 om-06, "Tensile properties of paper and paperboard (using constant rate of elongation apparatus)" [41]. Smoothness was measured according to TAPPI T538 om-08, "Roughness of paper and paperboard (Sheffield method)" [42]. Porosity values were obtained with TAPPI T547 om-07 (2007), "Air permeance of paper and paperboard (Sheffield method)" [43].

2.4 Testing Regime

For this study, 100 g/m² TAPPI handsheets were manufactured from the headbox pulp having a Canadian Standard Freeness (CSF) of 400 CSF. First, handsheets without any starch addition were created as a control.

Second, the impact of starch was evaluated at different concentrations and levels. For the unmodified pearl and cationic starch, starch was added at levels of 6.0, 18.0 and 24.0 kg/mt (12.0, 36.0, and 48.0 lbs./st) of fiber. For the applications of tapioca starch a three times lower rate of 2.0, 6.0 and 8.0 kg/mt (4.0, 12.0, and 16.0 lbs./st) was used, because tapioca starch tends to be 3 times more expensive as the unmodified pearl starch [26].

Third, handsheets were prepared for each starch by adding a) dry powder, b) cooked starch or heated starch for tapioca starch.

Fourth, the prepared handsheets were evaluated without contact drying and with contact drying to simulate the papermaking drying process, because the TAPPI 205 sp12 requires the handsheets to be fully dried at a Relative Humidity (RH) of 50% and 23°C from the wet state to equilibrium. Because, the industrial drying process influences paper properties process a Dayton Photo Dryer shown in Fig. 1. a) & b) was used. Fig. 1..c) Shows the temperature of the handsheet at 107°C and Fig. 1. d) The temperature of the felt/cylinder at the set temperature of 120°C.

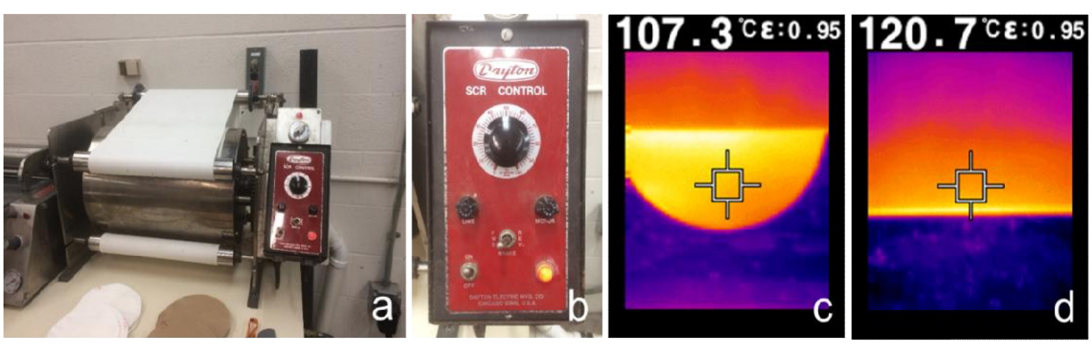

Fig. 1. a) Dayton photo dryer, b) Control unit, c) Handsheet drying, d) Drying felt/cylinder [44]

Fifth, Fines fractions of the pulp suspensions were evaluated for each starch at a 0.5% consistency using a Britt Jar devise with a 75 µm (200 mesh) screen according to TAPPI T261 cm-00 using five washing cycles with 500 ml deionized water. The remaining pulp on the screen was recover using a Büchner funnel with a 30 µm ash less filter paper. The solids content and ash content was determined using TAPPI T240 om-07 and TAPPI T211 om-02 respectively.

3. RESULTS AND DISCUSSION

3.1 Mechanical Properties

Hansheets at a basis weight of 100 g/m² were produce according to the testing regime described in section 2.5. using TAPPI test method T 205 sp-12, "Forming handsheets for physical tests of pulp" [28] and commercial prepared OCC paper fiber suspension collected from a paper machine headbox . All prepared paper handsheets were subject to standard atmospheric conditions according to TAPPI T 402 sp-13, "Standard conditioning and testing atmospheres for paper, board, pulp handsheets" [34] prior to testing. Physical testing of handsheets was carried out in accordance with TAPPI T 220 sp10, "Physical testing of pulp handsheets" [30]. Physical tests performed were a) burst strength indexes according to TAPPI T403 om-02, "Bursting strength of paper" [35], b) tear strength indexes according to TAPPI T 414 om-12, "Internal tearing resistance of paper (Elmendorf-type method)" [39], and tensile strength indexes according to TAPPI T 494 om-06, "Tensile properties of paper and paperboard (using constant rate of elongation apparatus)" [41].

3.1.1 Tensile index

Tensile index of the manufactured handsheets for all starch types and concentration and heating conditions is shown in Fig. 2.

Tensile index decreased for all additions of uncooked and cooked starch material between 0.00% and 1.48% with the exception for: a) the addition of uncooked peal starch at 36 lbs./st with an increase of 0.89%, b) uncooked cationic starch at an addition level of 12 and 36 lbs./st with an 13.09% and 5.35% increase respectively, and c) addition of uncooked tapiocas starch showed an increase of 14.28% at an addition level of 16 lbs./st.

Contact drying improved the tensile index for all additions of uncooked and cooked starch material. Uncooked pearl starch improved the tensile index by 12.20%, 18.15% and 17.85% for the addition of 12, 36, and 48 lbs./st respectively. Cooked pearl starch showed and improvement of the tensile index by 20.83%, 22.61, and 20.23% for the addition of 12, 36, and 48 lbs./st respectively. Uncooked cationic starch improved the tensile index by 23.21%, 29.76% and 24.10% for the addition of 12, 36, and 48 lbs./st respectively. The addition of cooked cationic starch resulted in an improvement of the tensile index by 10.11%, 11.90, and 11.28% for the addition of 12, 36, and 48 lbs./st respectively. Uncooked tapioca starch improved the tensile index by 15.77%, 9.22% and 35.71% for the addition of 4, 12, and 16 lbs./st respectively. The addition of cooked tapioca starch resulted in an improvement of the tensile index by 2.97%, 13.09%, and 11.90% for the addition of 4, 12, and 16 lbs./st respectively.

The highest tensile index improvement of 35.71% was for uncooked tapioca starch at an addition rate of 16 lbs./st, followed uncooked cationic starch at 29.76% for an addition rate of 36 lbs./st and cooked pearl starch at an addition rate of 36 lbs./st with a tensile index improvement of 22.61%.

3.1.2 Tear index

Tear index of the manufactured handsheets for all starch types and concentration and heating conditions is shown in Fig. 3.

Tear index decreased for the application of uncooked pearl starch by 3.50, 10.72, and 10.72% for the addition of 12, 36, and 48 lbs./st in comparison to the 0-paper handsheet tear index of 42.9 mNm²/g. The application of contact drying to the uncooked pearl starch resulted in an increase of the tear index by 0.70% for the 12 lbs./st addition and a decrease of 7.92 and 0.01% for the 26 and 48 lbs./st addition in comparison to the 0-paper handsheet tear index value of 42.9 mNm²/g.

For the addition of cooked pearl starch without contact drying a increase of 0.02 and 2.1% could be revealed for the addition of 12 and 34 lbs./st, respectively and a decrease of 0.7% for the 36 lbs./st addition based on the 0-paper handsheet tear index of 42.9 mNm²/g. Application of contact drying showed an increase of tear strength by 1.86% for the 12 lbs./st addition and a decrease

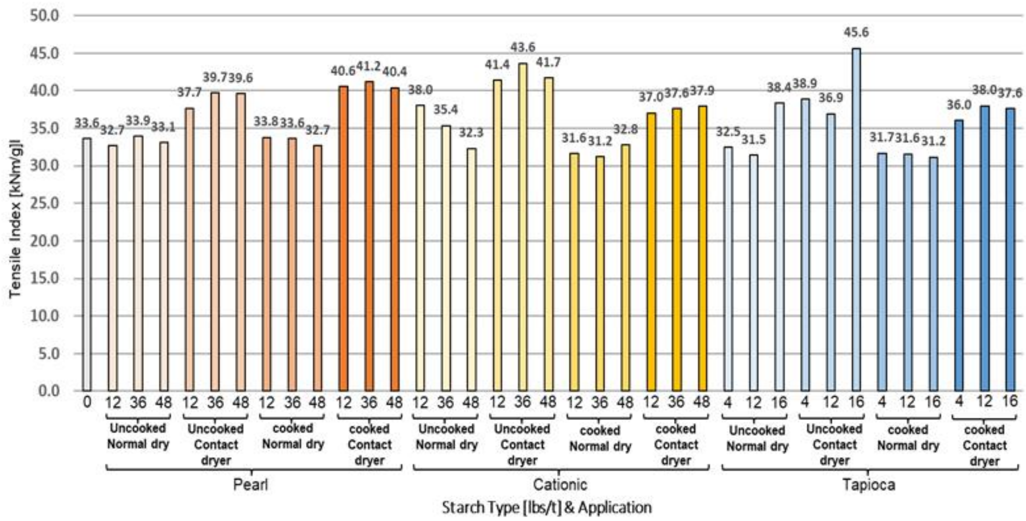

Fig. 2. Tensile Index for pearl, cationic and tapioca starch additions with and without

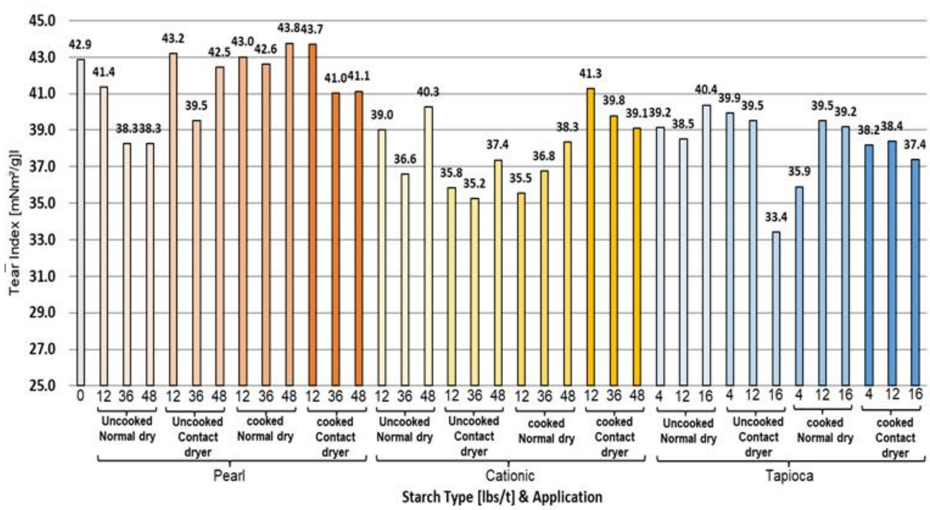

Fig. 3. Tear Index for pearl, cationic and tapioca starch additions with and without contact drying

Of 4.43 and 4.20% for the 36 and 48 lbs./st addition respectively based on the 0-paper handsheet tear index of 42.9 mNm²/g.

Tear index decreased for all additions of uncooked and cooked cationic and tapioca starch material including the application of contact drying.

Based on a tear index of 42.9 mNm²/g for the 0-paper handsheet the application of for uncooked cationic starch showed a decrease of 9.09, 14.68, and 5.39% based on the addition of 12, 36, and 48 lbs./st cationic starch respectively. Applying contact drying to the handsheets with uncooked cationic starch decreased the tear index further by 8.17, 3.82, and 9.16% based on the addition of 12, 36, and 48 lbs./st of cationic starch respectively.

The application of cooked cationic starch lowered the tensile index in comparison to the 0-paper handsheet by 15.48, 14.22, and 10.72% with an addition rate of 12, 36, and 48 lbs./st. By applying contact drying to the cooked cationic starch an increase of 16.24, 13.09, and 4.55% was revealed for a cationic starch addition of 12, 36, and 48 lbs./st respectively.

The addition of uncooked and cooked tapioca starch without contact drying decreased the tear index of 42.9 mNm²/g for the 0-paper handsheet by of 8.62, 8.97, and 5.83% for the uncooked tapioca starch addition rate of 4, 12, and 16 lbs./st respectively. For the cooked tapioca starch addition, a reduction of 16.32, 10.49, and 8.62% could be observed for addition rates of 4, 12, and 16 lbs./st respectively.

By applying contact drying to the uncooked tapioca starch handsheets an increase of 1.78, 2.60% for addition rates of 4 and 12 lbs./st, and a decrease of 17.33% for the 16 lbs./st addition rate in comparison to the handsheets with uncooked tapioca starch. Application of contact to the handsheets with cooked tapioca starch showed an increase of 14.37% for the application of 4 lbs./st, and a decrease of 2.78 and 4.59% for the addition of 12 and 16 lbs./st.

The highest tear index improvement of the produced handsheets was for pearl starch at an addition rate of 12 lbs./st in uncooked & contact dried, and cooked & contact dried with an improvement of 0.7 and 1.86% respectively.

3.1.3 Burst index

Burst index of the manufactured handsheets for all starch types and concentration and heating conditions is shown in Fig. 4.

Based on the 0-paper handsheet with a burst index value of 1.07.9 kPa·m²/g an increase of 19.60, 1.87, and 1.87% for the addition of 12, 36, and 48 lbs./st respectively was achieved for the addition of uncooked pearl starch. Application of uncooked cationic starch resulted in an increase of 10.28% for the addition of 36 lbs./st and a decrease of 4.67% for the addition of 48 lbs./st. The addition of 12 lbs./st of uncooked cationic starch resulted in an equal value in comparison to the 0-handsheet. The addition of uncooked tapioca starch resulted in an increase of 12.15, 7.48, and 16.82% for the addition of 4, 12, and 16 lbs./st.

Application of contact drying resulted in an increase of the burst index value of 1.07 kPa·m²/g of the 0-paper handsheet for the uncooked pearl, cationic and tapioca starch application. The increase was 21.49, 16.82, and 15.89% for the uncooked pearl starch and 33.64, 24.30, and 14.02% for the uncooked cationic starch at an addition rate of 12, 36, and 48 lbs./st respectively. Uncooked tapioca starch resulted in an increase of 7.48, 13.08, and 34.58% for the application of 4, 12, and 16 lbs./st respectively.

Application of cooked pearl, cationic and tapioca starch in comparison to the 0-paper handsheet burst index of 1.07 kPa·m²/g resulted in an increase of the burst index by 1.87 and 2.80% for the 12 and 48 lbs./st addition and an equal value to the 0-paper handsheet for the 36 lbs./st addition. The application of cooked cationic starch resulted in and equal value compared to the 0-paper handsheet for the 12 lbs./st addition. An increased value of 5.61% for the 36 lbs./st addition and a decrease of 2.80% for the 48 lbs./st addition. Cooked tapioca starch resulted in a decrease of 5.61% for the 4 and 12 lbs./st addition and a 7.48% decrease for the 16 lbs./st addition.

The application of contact drying showed an increase of burst strength in comparison to the 0-paper handsheet value of 1.07 kPa·m²/g for the addition of pearl, cationic and tapioca starch. Application of 12, 36, and 48 lbs./st of pearl starch increased the burst index by 20.56, 4.67, and 19.62% respectively. Cationic starch applied at a rate of 12, 36, and 48 lbs./st increased the burst index by 16.82, 14.96, and 11.21% respectively. Tapioca starch at an application rate of 4, 12, and 16 lbs./st increased the burst index by 13.08, 11.21, and 10.28% respectively.

The highest tear index improvement of the produced handsheets was for uncooked & contact dried cationic starch at an addition rate of 12 lbs./st with an improvement of 21.49%, and 16.82% for the uncooked & contact dried tapioca starch at an addition rate of 16 lbs./st.

3.2 Optical Properties

The commercial pulp used for this study is convert into a linerboard product to produce shipping boxes, and does not require additional treatment for color purpose. Therefore, only opacity values according to the TAPPI 425 om-06, “Opacity of paper (15/d geometry, illuminant A/2°, 89% reflectance” [40] was recorded for the different starch additions and handsheet treatments. Opacity is the masking effect of color or objects in the back of a paper sheet.

For all starch applications a) pearl and cationic starch at levels of 6.0, 18.0 and 24.0 kg/mt (12.0, 36.0, and 48.0 lbs./st) of fiber, and tapioca starch at level of 2.0, 6.0 and 8.0 kg/mt (4.0, 12.0, and 16.0 lbs./st), and b) additions.

As dry powder, b) cooked starch or heated starch for the tapioca starch, as well as c) prepared handsheets with and without contact drying the opacity range of all 100 g/m² handsheets was between 99.58% and 100% showing that now shine through effect can be recognized for either of the starches or treatment method.

3.4 Fines Retention

Fines retention of the commercial pulp was evaluated with a Britt Jar testing devise according to TAPPI T261 cm-00, “Fines fraction by weight of paper stock by wet screening” [40]. Pearl, cationic and tapioca starch products, applied in powder form are labeled “uncooked”. Starch products modified by cooking for the pearl and cationic starch and heat-treated for the tapioca starch are labeled “uncooked” in Fig. 5.

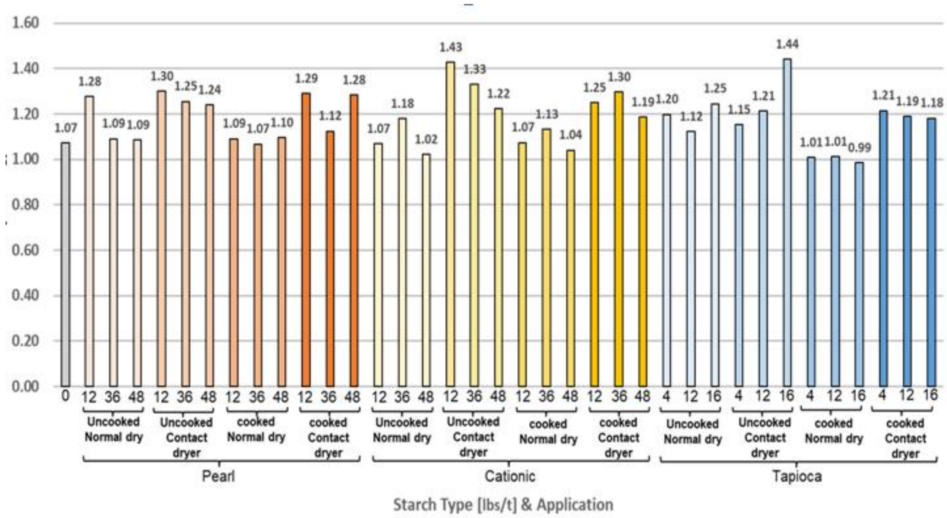

Fig. 4. Burst Index for pearl, cationic and tapioca starch additions with and without contact drying

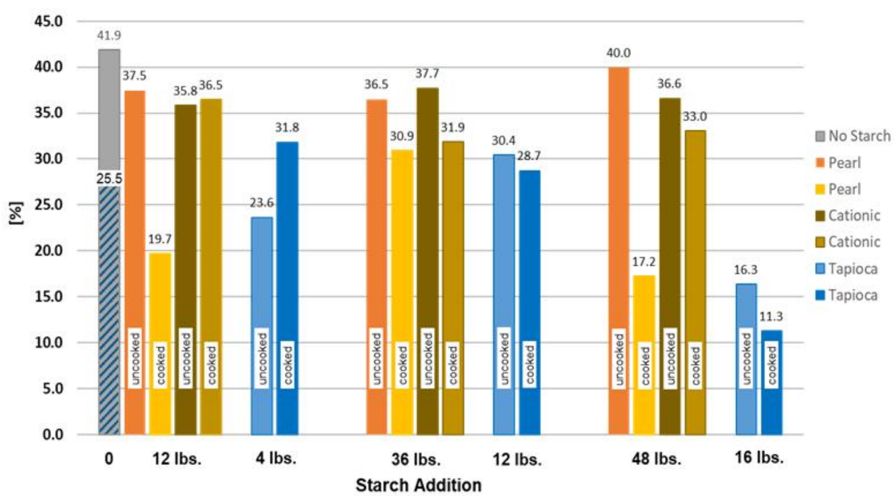

Fig. 5. Fines retention based on starch type and addition

The original pulp sample used for this part of the study without starch addition had a fine content of 41.9% for the pearl and cationic starch handsheet study and a 25.5% fine content for the tapioca handsheet study. For the pearl starch with an addition rate of 12.0, 36.0, and 48.0 lbs./st (6.0, 18.0 and 24.0 kg/mt) based on OD fiber content the fines content could be reduced to 37.5, 36.5 and 40.0% for the uncooked pearl starch addition, and 19.7, 30.9 and 17.2 respectively for the cooked pearl starch addition.

The cationic starch addition with a rate of 12.0, 36.0, and 48.0 lbs./st (6.0, 18.0 and 24.0 kg/mt) based on OD fiber, the fines content could be reduced to 35.8, 37.7 and 36.6% for the uncooked addition and reduced to 36.5, 31.1 and 33.0 respectively for the cooked starch addition.

The tapioca starch addition with a rate of 4.0, 12.0, and 16.0 lbs./st (2.0, 6.0 and 8.0 kg/mt) based on OD fiber showed a reduction of fines to 23.6 and 16.5% for the for the 4.0 and 16.0 lbs. for the uncooked addition, whereas the addition rate of 12.0 lbs. showed an increase of the fines content to 30.4% based on OD fibers. The cooked tapioca starch addition showed an increase of fine content to 31.8 and 28.7% for the addition of 4 lbs. and 12.0 lbs. respectively, and a reduction of fines to 11.3% for the 16 lbs.

Pearl and cationic starch addition showed a reduction in fines content for the uncooked and cooked application, whereas the 12 lbs. and 48 lbs. addition of cooked pearl starch outperformed all other additions with a reduction in fines content from 41.9 to 19.7 and 17.2 respectively. The addition of tapioca starch showed mixed results with a higher fine content for the addition at 4 lbs. for the cooked application and for the addition of 12 lbs. for the cooked and uncooked addition. A reduction in fines was achieved at an addition rate of 16 lbs. from 25.5% to 16.3 and 11.3% respectively for the uncooked and cooked addition.

3.5 Economic Evaluation

The economic evaluation shown in Fig. 6 used solely the fines retention numbers achieved with the commercial OCC pulp from section 3.4, but did not consider investment cost of equipment needed for adding the starch product to the machine chest. Fig. 6 shows the yearly Net Profit (NP) based on a 500 st/d production of paperboard using recycled OCC fiber material at a landing cost (LC) of $100 /st. and starch addition at the machine chest of the paper machine. A fines retention of 80% was assumed during the sheet forming process at the Fourdriner section (wet-end) of the paper machine. Starch prices incorporated in the economic evaluation are $0.18 $/lbs. for the unmodified pearl starch, $0.25 $/lbs. for the cationic starch, and $0.50 $/lbs. for the tapioca starch.

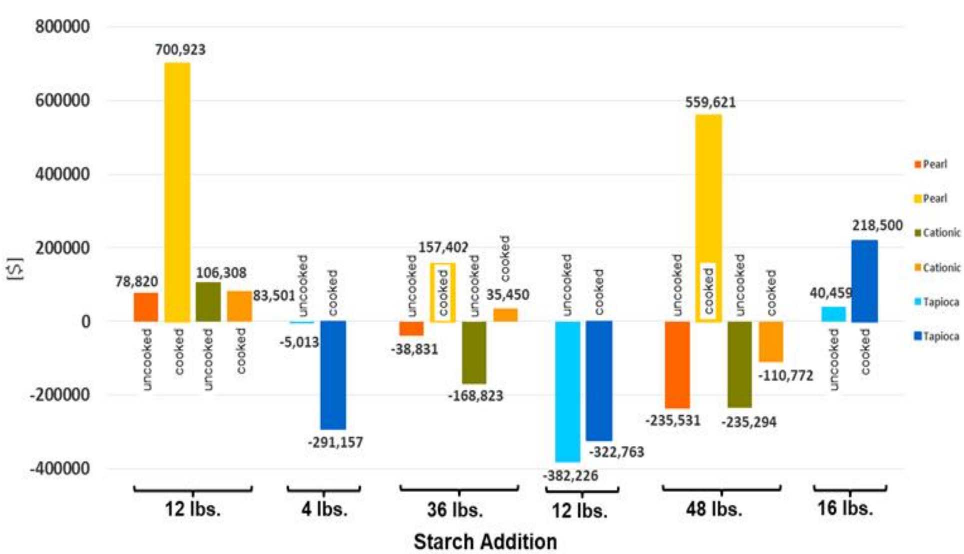

Fig. 6. Net Profit for pearl, cationic and tapioca starch addition

Cooked pearl starch outperformed the cationic and tapioca starch products at their respective addition rate. Pearl starch at an addition rate of 12.0 lbs./st showed the highest NP of $700,923, followed by an addition rate of 48 lbs./st with $559,621 NP. Pearl starch at an addition rate of 36 lbs./st revealed the fourth highest NP of $157,402, surpassed by tapioca starch with the third highest NP of $218,500 at an addition rate of 16 lbs./st. All other starch addition in cooked and uncooked form gave either negative NP or a NP below or close to $100,000.

4. CONCLUSION

100 g/m² TAPPI handsheets were manufactured from industrial processed OCC fiber material without starch and starch in cooked and uncooked form, air-dried and contact-dried at 120°C. Starch addition levels were 6.0, 18.0 and 24.0 kg/mt (12.0, 36.0, and 48.0 lbs./st) for pearl and cationic starch, and 2.0, 6.0 and 8.0 kg/mt (4.0, 12.0, and 16.0 lbs./st) for tapioca starch. Fines measurement was done with a Britt Jar devise having a 75 µm (200 mesh) screen.

Mechanical paper properties of hansheets tested showed the highest tensile index improvement of 35.71% for uncooked tapioca starch at an addition rate of 16lbs./st, followed by uncooked cationic starch at 29.76% for an addition rate of 36 lbs./st and cooked pearl starch at an addition rate of 36 lbs./st with an tensile index improvement of 22.61%.

The highest tear index improvement of the produced handsheets was for pearl starch at an addition rate of 12 lbs./st in uncooked & contact dried, and cooked & contact dried with an improvement of 0.7 and 1.86% respectively.

The highest burst index improvement of the produced handsheets was for pearl starch at an addition rate of 12 lbs./st in uncooked & contact dried, and cooked & contact dried with an improvement of 0.7 and 1.86% respectively.

The highest tear index improvement of the produced handsheets was for uncooked & contact dried cationic starch at an addition rate of 12 lbs./st with an improvement of 21.49%, and 16.82% for the uncooked & contact dried tapioca starch at an addition rate of 16 lbs./st.

Fines content was in general reduced with wet-end starch additions. Pearl starch showed the largest difference in fines content at the 12 lbs./st of fiber and 48 lbs./st of fiber concentrations, reducing fines content by 22.2% and 24.7% based on solids content respectively. Tapioca starch at 16 lbs./ ton of fiber concentration was able to reduce fines content by 14.2%. Cationic starch had the lowest reduction on fines content.

The economic evaluation showed that pearl starch outperformed the cationic and tapioca starch products at their respective addition rate. Pearl starch showed the highest NP of $700,923 at an addition rate of 12.0 lbs./st.

Unmodified pearl starch has the highest potential for strength improvements and fiber savings, while cooked and contact dried starches can deliver tensile and burst strength improvements. Low concentrations of unmodified pearl starch offered marginally different tensile strength, burst strength and fines retention values than high concentrations with the added benefit of higher tear strength. In addition, higher concentrations of starch as dry strength additives may increase mill costs without offering substantial operational cost benefits.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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43. TAPPI T547 om-07. Air permeance of paper and paperboard (Sheffield method).

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