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# Straw Paper for Art Applications – A Paper Development Study

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## ABSTRACT

Each paper grade, especially art papers have their own unique requirements by the artist using the paper in regard to mechanical integrity, surface topography, optical appearance and printability based on the unique artistic process applied during printing.

Wheat straw fiber, a left over product from agricultural operations, can be used in many papermaking grades if properly processed prior to papermaking.

A wheat straw containing art paper for artistic water color, oil, and encaustic (wax) painting applications was development and produced with a 10% and 15% northern bleached softwood content using a 12-inch (304 mm) wide laboratory scale paper machine, operated at a speed of 3.76 ft/min (1.14 m/min) with and without operating a calendar. The basis weight of the paper product was 350 g/m² with a caliper of 1050 µm to 1640 µm,

The paper products burst load in psi ranged between 2.49 and 4.71. Tensile peak load measured in kilogram-force (kgf) per 15mm wide testing strip ranged from 4.08 to 9.32 for the machine direction and 1.96 to 4.74 for the cross machine direction.

The roughness range of the wheat straw art paper was 2909 ml to 2963 ml for the top side and 2880 ml to 2954 ml for the bottom side of the paper.

The ISO brightness and opacity of the yellowish wheat straw art paper was at 22.74% and 100.00%, The ISO color value was for the L*, a*, b* Hunter color scale 69.46%, 02.02, and 15.47 respectively.

The finished art paper product met the expectations by the artists. The paper was used for several encaustic art studio projects.

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## 1. INTRODUCTION

Since the invention of paper in ancient China during the Eastern Han dynasty (105 CE) by Cai Lun [1]. Since it's invention it took more than a millennium to spread the art of papermaking over the world [2]. Paper as we know it today is produced with paper machines which can produce over 4,500 metric tons daily. These machines can be up to 600 m long and 11.5 meters wide and produce the paper speed at speeds of up to 2000 m/min [3-4].

In North America the most widely used fiber for paper making are wood fiber from leaf trees called Hardwood (HW) fiber and needle trees called Softwood (SW) fibers. Other materials are added to the paper fiber slurry to enhance the produced paper properties such as filler materials, color pigments, and chemical additives based on the specific product requirements [5-6].

To extract the cellulosic fibers a process called Kraft pulping is used. The Kraft process was invented and patented by the German Scientist Carl Friedrich Dahl in 1879 [7]. Kraft pulping has been used commercially first in Sweden in1885 [8]. Since then, the Kraft process has been developed and improved and is today the most common chemical extraction process, for cellulosic fiber material worldwide applied to SW and HW fiber materials [9].

However, many areas of the world do not have the wood fiber resources that are available in the North America. For these areas a possible substitute is for cellulosic fiber material cold be straw.

According to the United Stated Department of Agriculture (USDA), wheat production ranks 3rd among U.S. field crops. In 2020 about 1.8 billion bushels (48,987,900 metric tons) of wheat products were harvested on an are of 36.7 million acres (148,519.6 km$^2$) [10].

In 2020 the United States ranked 9th with 4.59% market share in wheat straw exports, surpassed by Spain (17.49%), France (12.3%), Australia (10.77%), Pakistan (10.24%), Germany (6.5%), Poland (5.81% and the Netherlands (4.59%). Denmark ranked 10th with 3.59% on a total exported value of $278.64 million among the top 10 wheat straw exporters [11].

Historically, the value of straw was so low compared to the cost of harvesting, that most farmers burned the straw fields to the ground. This did serve two important functions, reducing soil erosion and returning nutrients and organic matter back into the soil. If it was harvested, the straw was often used as animal feed. Between government subsidies and technological advancements, other avenues have become available. Examples include producing heat & electricity, ethanol, methanol, building material, and paper products [12].

Straw fiber can be used in many papermaking grades. It can be often found in paper produced for board and packing grades. New application can be found in sustainable copy and packaging paper, tissue, towel and molten fiber application solutions [13-16].

Producing paper products from wheat straw is still uncommon in industry, but there are a few mills that are having some success. Columbia Pulp [14], Step Forward Paper [15], and Tranlin Inc. [16] are three that stand out.

The wheat straw market base is targeting customers that are more environmentally conscious. Companies selling these products tote their environmentally friendly benefits such as being Chlorine-Free, compostable, tree-free, reduced emissions/energy usage/chemical usage, dye-free, BPA-free, and in addition supporting local farmers [14-16].

Tranlin Inc. is a Chinese paper company that manufactures goods out of 100% straw. Their products include facial and bath tissue, bowls, plates, and napkins. Tranlin Inc. prides itself in making papers that are tree-free, chlorine-free, and unbleached. In addition to selling paper, Tranlin Inc. also sells the nutrients it extracts as organic, high nutrient fertilizer [16]. On the other side of the spectrum, Step Forward Paper makes copy paper using 80% wheat straw and 20% wood fiber and professional grade paper for large scale commercial printing papers using 60% wheat straw and 40% wood fiber [15]. Columbia Pulp is the first tree free pulp mill in the U.S. located in Dayton, WA that utilizes some of the 4.5 million tons of wheat straw produced annually in a 100-mile (160.9 km) perimeter around Dayton. The Columbia Pulp mill is anticipated to produce 140,000 dry US tons (127,005.9 metric tons) of wheat straw wet lab pulp from 250,000 US-tons (226,796.2 metric tons) of raw wheat straw annually, eliminating the burning of the associated wheat straw fields annually. The produced Columbia Pulp can be used for applications in the paper, board and tissue industry [13-14].

Straw can be pulped using many of the modern chemical methods including Kraft, sulfite and soda-aq pulping. In order to separate the fibers, the straw is cooked using steam and caustic soda (NaOH) [17]. Chemically pulping wheat straw is the most prevalent method used today and this is often done in a caustic solution [18-20]. To increase the effectiveness for lignin removal and cellulose yield of the pulping process chemicals used, pulping is carried out in large pressurized vessels [8].

Each paper grade, especially art papers have their own unique requirements by the artist using the paper in regard to mechanical integrity, surface topography, optical appearance and printability based on the unique artistic process applied during printing.

Due to limited available equipment an open soda cook was the most feasible option for this research with the goal of developing an specialized art paper product for the application of encaustic painting which is also known as painting using hot wax including clear or pigmented paraffin wax, beeswax incorporating colored dry pigments, inks, oil paints or any other suitable additive for color enhancement. The hot molten wax is applied to receiving surface, in our case the wheat straw paper product with tools such as paint brushes, spatulas, knives and scrapers as well as modify and model the applied wax during and after cooling.

The following manuscript describes the development of an wheat straw based art paper for encaustic art painting applications. Such a paper is not available commercially and represents a new art paper product.

## 2. MATERIAL AND METHODS

The following materials and methods were used for the straw art paper grade development.

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### 2.1 Materials Used

For the development of the straw art paper product, local wheat straw from a farm in the Syracuse, New York area was used as the selected fiber material. Northern bleached softwood pulp with an 80% Black Spruce and 20% Jack Pine mixtures, having a ISO Brightness of 89.5% and an average fiber length of 2.26 mm, was used as a supplemental fiber material.

Unmodified corn starch was used as retention, sizing and strengthening agent. The starch was cooked at 95˚C - 98˚C (203°F - 208°F) as a 3% solution. 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 [21-22].

Sodium Hydroxide (NaOH) pellets were used to prepared a 10N (30%) solution prior to applying. 98.5% Dimethyl quinone powder was used as additional pulping chemical for cooking the straw fiber material. It was added at 0.19% to the solution based on oven dry (OD) fiber content. [18-20].

### 2.2 Testing Methods

In this study the following testing methods of the Technical Association of the Pulp and Paper Industry (TAPPI) and International Organization for Standardization (ISO) were used:
Beating of pulp (Valley beater method) in accordance to T 200 sp-06 “Laboratory beating of pulp (Valley beater method)” [23].

Handsheets were prepared according to TAPPI T 205 sp-12, “Forming handsheets for physical tests of pulp” [24]. Physical testing of handsheets was performed in accordance with T 220 sp-06, “Physical testing of pulp handsheets” [25]. Freeness of pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09 “Freeness of pulp (Canadian standard method)” [26]. Consistency of the pulp suspensions was measured with TAPPI T 240 om-07 “Consistency (concentration) of pulp suspensions” [27].

Zero-span breaking strength was measured according to TAPPI method T231 cm-07, “Zero-span breaking strength of pulp (dry zero-span tensile) [28].

Screening of pulp was performed in accordance to T 274 sp-08, “Laboratory screening of pulp (Master Screen-type instrument)” [29], the instrument used was a Valley type Screen with a 350 µm screen plate and a Voith Valley screen with 150µm screen plate.

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” [30].

Burst Strength was measured in accordance with T 403 om-02, “Bursting strength of paper” [31]. Basis weight was measured with T 410 om-08. “Grammage of Paper and Paperboard (weight per unit area)” [32]. Thickness of the paper was measured with TAPPI T 411 om-10. “Thickness (caliper) of paper, paperboard, and combined board” [33].

Moisture content of pulp was determined by T412 om-06 “Moisture in pulp, paper and paperboard” [34].
The tear strength was done by following the T 414 om-12, “Internal tearing resistance of paper (Elmendorf-type method)” [21].

Tensile strength was evaluated using TAPPI method T 494 om-06 Tensile properties of paper and paperboard (using constant rate of elongation apparatus) [35].

Surface roughness of the paper product was measured with TAPPI method T 538 om-08 “Roughness of Paper and Paperboard (Sheffield method)” [36]. Brightness was measured according to ISO 2470 “Paper, board and pulps - Measurement of diffuse blue reflectance factor – Part 1: Indoor daylight conditions (ISO Brightness) [37]. Opacity was determined according to ISO 2471:2008 Paper and Board: Determination of Opacity (Paper Backing) – Diffuse Reflectance Method [38].

Whiteness/Color was measured according to ISO 11476:2016 Paper and Board – determination of CIE Whiteness, C/2° (Indoor Illumination Conditions) [39].

Dryer can temperature of the 12-inch paper machine was controlled with build in temperature controllers.

## 2.3 Wheat Straw Art Paper Handsheet Development Procedure

The Process wheat straw preparation includes all process used to take the straw from its original form until it is diluted to its final consistency and ready for making paper. Fig. 1. Shows the wheat straw process flow for handsheet preparation and final papermaking on a small 12-inch-wide laboratory paper machine.

### 2.3.1 Mechanical cutting and disintegration

Wheat straw fibers used had a length of up to 14 inch (356 mm), to long for a mechanical disintegration or also called refining operation. It was determined by tests that wheat straw fibers with an approximate length of 1 inch to 4-inch (25 mm to 100 mm) give best refining results using a 12-inch (305 mm) diameter Sprout Bauer laboratory single disk refiner operating with a 4 mm (0.158 inch) gap between the disks. All wheat straw for this research was cut to a length of 1 inch to 4 inch (25 mm to 100 mm), presoaked and then refined with the Sprout Bauer laboratory refiner at a disk gap of 4 mm.

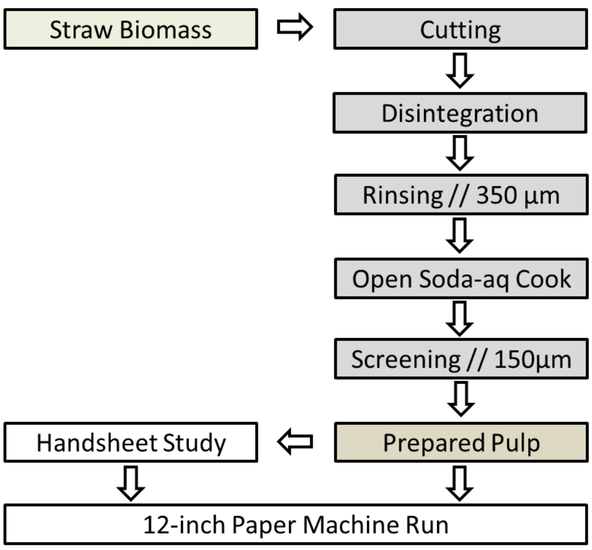


**Fig. 1. Wheat straw processing flow chart**

After refining the fibers were sent through a Valley type Screen with a 350 µm screen plate according to TAPPI method T 274 sp-08 to screen out debris and remaining large fibers that did not refine well.

#### 2.3.2 Chemical pulping

Laboratory chemical pulping was performed at a fiber to liquor ratio of 1:15 for 8 hours in open 4-liter stainless steel containers heated with a heating plate. The wheat straw fiber suspension containing the pulping chemicals was kept at a temperature between 198°F to 208°F (92.2°C to 97.8°C), was hand stirred, and the evaporated water was replaced periodically.

Upscaling of what straw pulping was done using a 50-gallon (189 l) steam jacketed cooking kettle, able to process up to 17 lbs (7.72 kg) per cook.

After the wheat straw laboratory 4-liter and 50-gallon (189 l) steam jacketed kettle cook the wheat straw pulp was washed to remove the pulping chemicals. After washing the wheat straw pulp was screened with a Voith Valley screen with 150 µm screen plate according to TAPPI method T 274 sp-08.

For both the laboratory and upscale cooking operation, the pulped wheat straw fibers were then dewatered with a cheese cloth, hand crumbed and stored in a cold room at 41°F (5°C) at a moisture content of approximately 85% for the later handsheet making.

#### 2.3.3 Laboratory handsheet preparation, refining and testing

Handsheet from the pulped and later refined wheat straw were made and tested according to the referenced TAPPI test methods in Section 2.3.

### 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 follows to procedure from a previous publications from Dölle & Rainville [40], with the set-up of the LFPM system described as follow:

#### 2.4.1 Stock Preparation System

The stock preparation of the LFPM, shown in Fig. 2., consists of a 5 hp (3.73 kW), 35 gal (132.5 l) low consistency pulper, a 3 hp (2.24 kW) transfer pump, a 10 hp (7.46 kW) low consistency conical Jordan refiner, and two storage chests with a usable volume of 240 gal. (908.5 l) each, and a propeller agitator with 1.5 hp (1.12 kW). The chests can be operated separately or together. Additives for papermaking can be added either in the pulper or the storage chests.

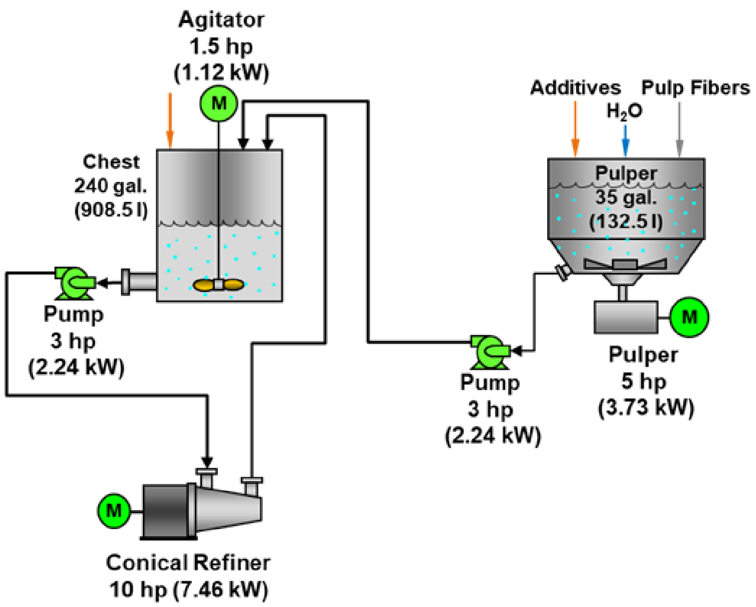


**Fig. 2. Laboratory stock preparation system [40]**

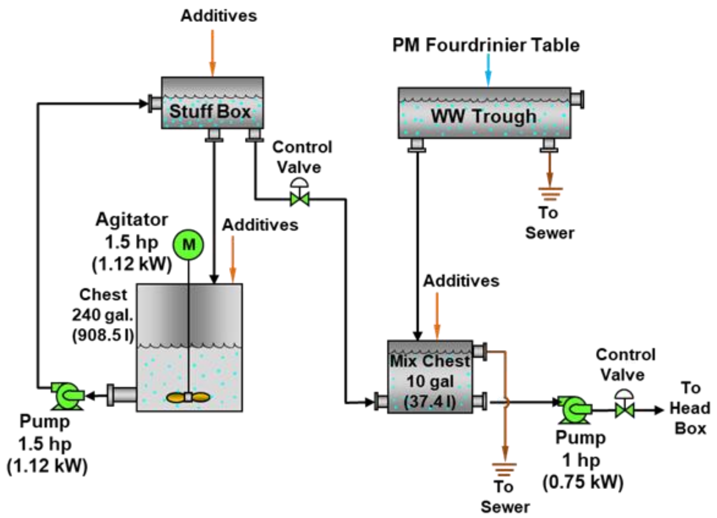


**Fig. 3. Wet End of the 12" laboratory Fourdrinier paper machine [40]**

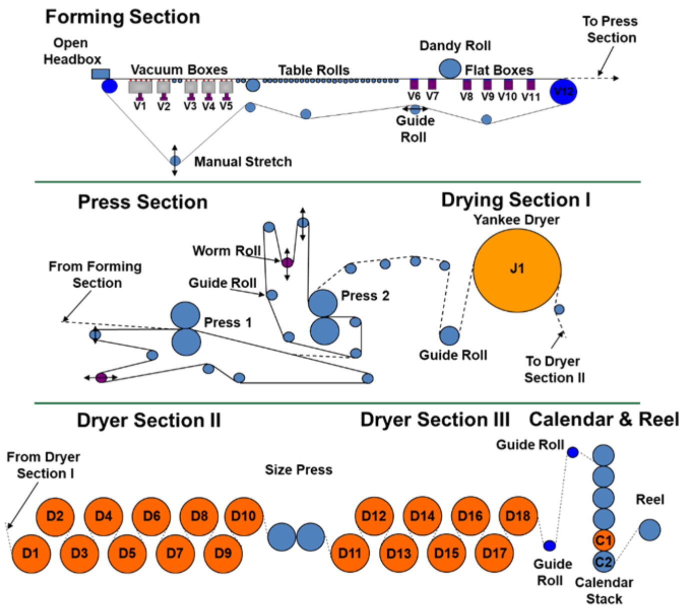


**Fig. 4. Laboratory Fourdrinier paper machine [40]**

### 2.4.2 Wet End System

The wet end of the LFPM, shown in Fig. 3. consists of the two storage chests with a usable volume of 240 gal. (908.5 l) each, and a propeller agitator with 1.5 hp (1.12 kW). The 2 storage chests serve as the LFPM machine chest. Additives might be added at the machine chest as needed. The chests can be operated separately or together. An impeller transfer pump with 1.5 hp (1.12 kW) supplies the prepared fiber suspension to the stuff box. Additives might be added at the stuff box as needed. From the stuff box the fiber suspension is metered into the 10 gal. (37.4 l) mix chest, where additives might be added as needed. Part of the fiber suspension from the stuff box is recirculated to the machine chest. In the mix chest the fiber suspension is diluted with the white water from the LFPM white water trough. A possible overflow is transferred to the sewer. An impeller pump with 1 hp (0.75 kW) transfers the final prepared fiber suspension to the LFPM for papermaking.

### 2.4.3 12"Laboratory Fourdrinier Paper Machine

The LFPM shown in Fig. 4. was used to upscale the produced art paper from the handsheet study.

The LFPM features a 70 inch (1778 mm) long Fourdrinier section followed by a 2-nip press section. After the press section, there is a dryer section with a Yankee dryer (J1), followed by a 1st and 2nd dryer section with 10 (D1-D10) and 8 (D12-D18) electric heated dryer drums. Each dryer drum can be heated to up to 343°C (650°F). Between the 1st and 2nd dryer section a size press is located. A 6-roll vertical calendar stack, of which on roll (C2) can be heated is located after the dryer section followed by the reel. The LFPM wet end has an total installed electrical power of 4 hp (3.0 kW) and the LFPM has a total installed power of 30 hp (22.5 kW). The LFPM can produce a finished paper product with a basis weight between 20 g/m² and 750 g/m² at a speed of up to 8.0 m/min.

## 3. RESULTS AND DISCUSSION

All tests for this research and development project were performed in accordance to the in Section 2.2. referenced TAPPI and ISO methods. All results stayed in the precision statements for the referenced TAPPI and ISO methods.

### 3.1 Handsheet Development

#### 3.1.1 Wheat straw laboratory cooking

For the laboratory scale wheat straw cooks the remaining variable left to test was the concentration of the sodium hydroxide. Three separate four-liter containers were set for the wheat straw fiber cook. The three levels of sodium hydroxide to be tested were 10%, 20% and 30%. These cooks were carried out for 8 hours each using 100 g OD wheat straw fibers. Handsheets were created from the resulting pulps. However, the handsheets from these pulping methods produced low quality paper. After further research and discussion, it was determined that a pulping additive was needed to increase the effectiveness. The pulping additive was chosen to be dimethyle quinone.

A second set of three laboratory cooks were carried out for 8 hours between 198°F to 208°F (92.2°C to 97.8°C) as described in 2.3. Based on data from the first laboratory cooks it was determined that a NAOH concentration of 25% would be ideal, plus 0.15% dimethylquinone, both based on OD wheat straw fiber content. The 222.7 g was of satisfactory quality and would be used to scale up to a larger cook to determine refining and final handsheet properties.

### 3.2 Wheat Straw Scale-Up Cooking Operation

The small lab scale pulping operation was sized up for the small 12-inch laboratory paper machine run.

For this 51 lbs (23.2 kg) of wheat straw were cut to a size of 4 cm and wetted with approximately 200 lbs of water to a chive a solids content of 20% for refining. The 20% whet straw suspension was refined with a 12-inch (305 mm) diameter Sprout Bauer laboratory single disk refiner with a disc gap of 4 mm (0.157 inch). After refining the fibers were sent through a Valley type screen with a 350 µm screen plate according to TAPPI method T 274 sp-08. The screen helped to screen out large fibers that did not refine as well as any debris. The rejects consisted of mainly large pieces of unrefined straw or larger fiber bundles. These were passed through the refiner again at a gap of 0.020- inch (0.5 mm) and then screened a second time. The remaining rejects were passed through the refiner a third time and screened. Accepts from all three screenings were combined to produce the final wheat straw pulp for the soda-aq open kettle cook. A 50-gallon (189 l) steam jacketed cooker, able to process up to 17 lbs (7.72 kg) of wheat straw at a time was used for the three needed open kettle cooks. The wheat straw open kettle soda-aq cook contained 25% NaOH and 0.15%% dimethyl quinone based on OD wheat straw fiber mass. Each cook was run for 8 hours at a temperature between 198°F to 208°F (92.2°C to 97.8°C). After the wheat straw soda-aq open kettle cook the cooked wheat straw pulp was washed to remove the pulping chemicals. After washing the wheat straw pulp was screened with a Valley type Screen having a 350 µm screen plate and a Voith Valley screen with 150µm screen plate and dewatered by hand using a cheese cloth fabric.

The final fibers were then crumbed and stored for later use in a cold room at 41°F (5°C) at a moisture content of approximately 85%. During stock prep this dewatered pulp is pulped at 5% consistency, refined at 3% consistency, and dispersed to the paper machine chest consistency of 1.5%. The processing efficiency of the complete wheat straw fiber preparation was 43%. Table 1 the individual major process steps and yield accordingly.

**Table 1. Wheat Straw Processing Yield**

| | Straw | Copped | Refined Straw | Cooked/Rinsed Straw | Screened Straw |
|---|---|---|---|---|---|
| Wet Mass (lbs/kg) | 51/23.1 | 50/22.7 | 251/113.9 | 554/251.3 | 131/59.4 |
| Moisture Content | 8.10% | 8.10% | 83.50% | 95.7% | 84.5% |
| OD Fider (lbs/kg) | 47.1/21.63 | 46.2/20.8 | 41.8/18.6 | 22.5/9.9 | 20.3/9.1 |
| Stage Yield | N/A | 98.2% | 90.4% | 53.8% | 90.2% |
| Overall yield | N/A | 98.2% | 88.8% | 47.7% | 43.0% |

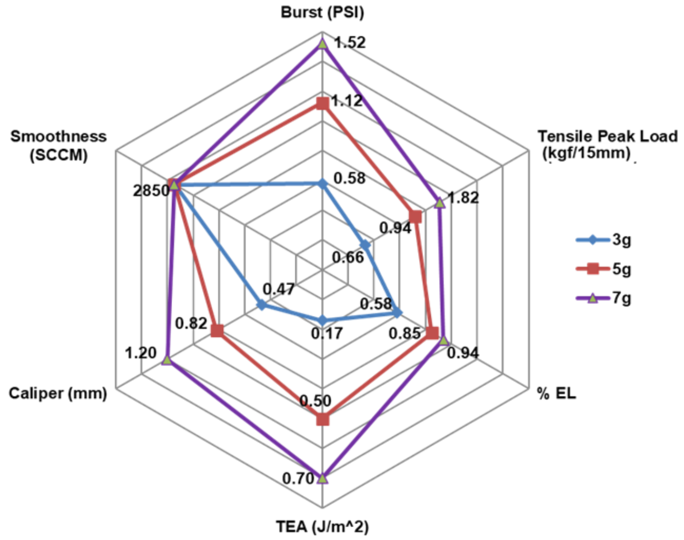


**Fig. 5. 100% Wheat straw handsheets**

## 3.3 Wheat Straw Pulp Refining for Papermaking

Refining of paper fiber is needed to develop the paper fibers mechanical strength. Following the TAPPI T 200 testing method, the pulped wheat straw fibers were refined for hand sheet making. Based on past 12-inch laboratory machine data suggest that the lowest freeness typically ran on the paper machine is in the 300 ml to 400 ml CSF area. It was determined that 6 minutes of refining to a CSF level of 300 ml is sufficient for the wheat straw fibers. A refining time of 9 minutes resulted in a large amount of fines produced. This made it very difficult to remove the handsheet formed the 150 mesh (89µm) forming wire of the TAPPI sheet maker due to picking, which destroyed the formed handsheets during couching.

## 3.4 Wheat Straw Handsheet Making

Handsheet forming was done according to TAPPI method T-205 sp-12 with a variations that matched the unique wheat art straw paper process. In the T 205 method the handsheet basis weight is 60 g/m², requiring a OD fiber weight of 1.2 g in the fiber suspension that is used to make the handsheet. The wheat straw art paper required a higher basis weight, therefore handsheets were made with 3 g, 5 g, and 7 g of OD fibers in the suspension representing a basis weight of 150 g/m², 250 g/m², 350 g/m² respectively. This to represent the target basis weight for the later 12-inch laboratory paper machine production.

### 3.4.1 100% Wheat Straw Handsheets

After analyzing lab data from the 100% wheat straw handsheets, it was apparent that the basis weight increases from 3 g (150 g/m²) to 5 g (250 g/m²) and further for the 7 g (350 g/m²)showed a significant improvement for the strength properties. Burst Strength and Tensile Energy Adsorption (TEA) showed most dramatic increase, while Elongation (EL) had less of a substantial increase as shown in Fig. 5. While the strength measurements were far below expectations for the produced handsheets, it served to show the bottom range of allowable basis weight to manufacture paper from the pulped wheat straw fiber material. In addition, Fig. 5. also displays an expected increase in caliper with increasing basis weight while smoothness remained fairly consistent near 2850 Standard Cubic Centimeters (SCCM) for the smooth side (polished metal disc side) as expected.

The opacity of the yellowish wheat straw handsheets was at 97.63%, 98.71%, and 99.11% for the 3 g (150 g/m²), 5 g (250 g/m²) and 7 g (350 g/m²) handsheets respectively.
ISO brightness level according to the ISO 2470 was measured at 22.82%, 23.04%, and 23.02% for the 69.83% and 3 g (150 g/m²), 5 g (250 g/m²) and 7 g (350 g/m²) handsheets respectively.

The colour value according to the ISO 11476 method for L*, a*, b* was at 23.85%, 2.28, and 23.63 for the 3 g (150 g/m²), 67.34%, 2.35, and 23.03 for the 5 g (250 g/m²) and 67.49%, 2.23, and 22.2 for the 7 g (350 g/m²) handsheets.

### 3.4.2 100% Straw Handsheets with Starch

Fig. 6. shows the laboratory test data related to the addition of 15% starch as wet and dry strength agent to the handsheets. For the starch addition handsheets with 4 g (200 g/m²), 5 g (250 g/m²), 6g (300 g/m²) and 7 g (350 g/m²) were manufactured. An irregularity was observed regarding the caliper measurement as the 5 g (250 g/m²) sheet was shown to be thicker than the 6 g handsheet. This abnormality was attributed to issues of 'picking' as previously discussed when handsheets where being removed from the forming screens. Most strength properties showed at least a 50% improvement with the addition of starch, compared to the 100% straw handsheets only. The higher grammage handsheets showed greater strength improvements, especially in TEA and % EL. The 7 g (350 g/m²) handsheet showed the most significant improvement performing much better than the 6 g (350 g/m²) in TEA and %EL, while having expected linear improvement in Tensile Peak Load and Burst. The addition of starch had no effect on the Sheffield smoothness of the handsheets with values in proximity to 2850 (SCCM).

Based on the handsheet laboratory results the 7 g (350 g/m²) handsheet showed the best most promising results for papermaking with the 12-inch laboratory paper machine. Optical tests performed for the different basis weight handsheets showed a less than 1.5% difference for opacity, less than 1% difference for the brightness, and similar values for the colour of the handsheets. The Opacity for the 7g (350 g/m²) was measured at 99.11%. The ISO 2470 brightness was measured at 23.02%.
The colour value according to the ISO 11476 method for L*, a*, b* was at 67.49%, 2.23, and 22.2 for the 7 g (350 g/m²) handsheets.

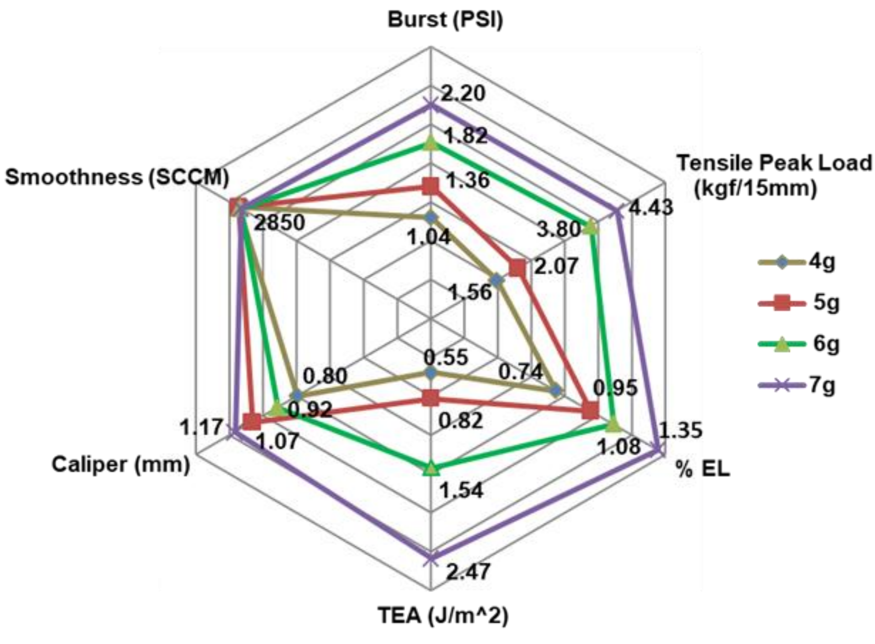


**Fig. 6. 100% Wheat straw handsheets with 15% starch**

### 3.5 Wheat Straw Art Paper Properties based on Laboratory Development

Based on the laboratory handsheet development, the pulped wheat straw fiber will need to be beaten to 300 ml CSF. Starch was added as retention and strength agent at 10% based on OD wheat straw fiber content. No other additives will be added to the pulp suspension during the papermaking process. The artists request for the paper to be able to be more on the heavier side it was decided to test for basis weight using TAPPI T410 method [32]. Thickness was tested using TAPPI T411 method [33]. Basis weight and thickness target were set at 350 g/m², and 1000 µm respectively. The finished moisture content of the paper should be in the range of 90% to 95% measured with TAPPI method T412 [34].

To ensure the strength integrity, tensile and burst load tested according to T494 and T403 became a necessary to ensure that the paper would be strong enough to be used in printing presses at the artists facility without failure [31,35]. The targeted tensile and bust load was set 4.5 kgf/15mm and 2.5 psi respectively. I was decided by the artist that roughness, according to TAPPI test method T 538 [36] had to be measured as a key surface property requirement for printing. The roughness target value was set to be 2900 ml/min for the top side and wire side, measured according to T538 testing method [36].

The color target for the yellowish straw colour was set at ISO brightness level according to the ISO 2470 at 23.00% and a colour value according to the ISO 11476 method for L*, a*, b*. at 67.00, 2.20, and 22.00 respectively.

### 3.6 12-inch Laboratory Fourdrinier Paper Machine Run

The LFPM run is using the prepared 21.2 lbs of wheat straw pulp as well as 6.5 lbe. of NBSK pulp fibers as a supplemental fiber material. The prepared fiber material allowed a maximum LFPM run time of approximately 4 hours, producing a paper sheet with a basis weight of 350 g/m² and a caliper of 1000 µm. This will leave enough time to start-up the LFPM, make needed adjustments to meet paper properties, and produce enough paper for a printing evaluation by the artist.

For the LFPM run the 21.2 lbs (9.6 kg) OD of pulped wheat straw and 6.5 lbs (2.9 kg) NBSK virgin pulp fiber material was pulped as follow: First, the 21.2 lbs (9.6 kg) of pulped wheat straw was pulped 15 minutes at 20°C in two batches of 25.4 gal (96.0 l) each at a consistency of 5% using the 35 gal (132.5 l) low consistency laboratory pulper of the LFPM stock preparation system. After pulping the wheat straw suspension was transferred into the 1$^{st}$ 240-gal (908.5 l) storage chest and diluted to a consistency of 3% by adding 33.8 gal. (128.0 l) of water at 20°C to achieve a total wheat straw suspension volume of 84.6 gal (320 l) at 3% consistency for refining. Second, the 6.5 lbs (2.9 kg) of NBSK was pulped in the 35 gal (132.5 l) low consistency laboratory pulper at a consistency of 3% by adding 25.6 gal. (96.7 l) of water at 20°C. After 10 minutes of pulping the NBSK pulp suspension was transferred into the 2$^{nd}$ 240-gal (908.5 l) storage chest.

Third, the wheat straw and NBSK pulp slurry was then refined to a CSF value of 200 ml from 3000 ml and the NBSK was refined from a 750 ml CSF value to 540 ml with a Jordan conical refiner under a 1.5 Amp net load by carefully monitoring in 5-minute intervals. CSF value was measured with TAPPI test method T 227 om-09. After refining the wheat straw and NBSK fiber slurry was diluted to a machine chest consistency of 1.5% by adding 84.7 gal (320.0 l) of water at 20°C to the wheat straw pulp and 25.6 gal (96.7 l) of water at 20°C to the NBSK pulp. This resulted in 169.2 gal (640.0 l) of the wheat straw suspension and 51.2 gal (193.4 l) NBSK pulp fiber mixture at 1.5% consistency available for the wheat straw art paper production.

Fourth, eight pounds of oven dry unmodified corn starch were prepared as sizing and retention agent using a jet cooking apparatus which cooked the starch solution at 3.5% between 95°C and 98°C (203°F and 208°F) for ten minutes. After cooking the starch solution was then diluted to a consistency of 0.1% using deionized water at 20°C to eliminate bacterial growth. The resulting 9.6 gal (36.3 l) of 0.1 % starch solution was filled in to 5 gal pails. During the LFPM run the 0.1% starch solution was added with a peristaltic pump at the 10 gal. mix chest, shown in Fig. 5, to achieve a 0.3% starch addition based on OD fiber content.

No additional retention aid was used due to the high retention rate (above 80%) of the LFPM.

Fifth, the final production run of the LFPM paper machine was executed under the following conditions:

a) The LFPM was operated at a speed of 3.76 ft/min (1.14 m/min) for the straw art paper production run. Vacuum levels for the fourdrinier table 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 final fiber flow to the headbox at a consistency of 1% was set at 1.1 gal/min (4.15 l/min) to achieve the desired basis weight of 120 g/m² for the wheat straw art paper product.
b) The 1st and 2nd press was operated at 30 psi (206842 Pa) and 60 psi (413685 Pa) for all adjustment of the art grade.

c) The heat of the Yankee-Dryer (J1) in dryer section 1 was kept at 160.0°C (320°F). The heat for the dryers in dryer section 2 is kept at 165.6°C (330°F) for the 1st to the 5th dryer (D1-D5), 176.6°C (350°F) for the 6th and 7th (D6 & D7) dryer, no heat was applied to dryer 8th and 9th (D8 & D9) by setting the electronic heating module to 15.0°C (50°F). For the 10th, 11th, 12th, and 13th (D10, D11, D12 & D13) dryer the heat was set to 182.2°C (360°F). In dryer section 3 no heat was applied to the 14th and 15th (D14 & D15) dryer by setting the electronic heating module to 15.0°C (50°F). The 16th,17th, 18th, and 19th (D16, D17, D18 & D19) dryer, the heat was set to  and 182.2°C (360°F).

d) The calendar section operated without pressure and heat. At the end of the LFPM wheat straw art paper run the calender section was operated at 20 psi (137895 Pa), and 30 psi (206843 PA), to evaluate the impact of calendering on the final wheat straw art paper properties.

e) After the calendering section the straw art paper was rolled up and the paper rolls were conditioned according to TAPPI Test method T402 before cut in size for testing and print evaluation. Additional testing was done without conditioning of the paper samples for comparison.

### 3.7 12-inch Laboratory Paper Machine Wheat Straw Art Paper Testing Results

Prior to the 12-inch laboratory paper machine run initial testing was performed.This tests showed that 100% straw paper does not show good run ability on the paper machine. It was decided to add 10% Northern bleached softwood Kraft (NBSK) pulp. The NBSK was pulped and refined from a CSF value of 750 ml to a CSF value of 540 ml. Once the pulp was refined it was added to the straw pulp until a mixture of 90% straw and 10% softwood was achieved. This increased the wet strength of the paper and the sheet then under the same conditions easily made it to the reel. There were still minor picking issues at the first press so an additional 5% of softwood by mass was added, creating an furnish of 85% straw and 15% softwood. The paper was at the reel with ease, and an uneven moisture profile had developed at the reel. Dryer temperatures were then increased by an average of 20%. This improved the drying issues. Two nips of the calendar stack were then applied at 20 psi (137895 Pa) which increased smoothness and reduced caliper. Calendaring was then increased to 30 psi (206842 Pa) to further increase the smoothness of the produced art paper.

During the 12-inch laboratory paper machine operation nods, shown in Fig. 7, built up over the course. The areas highlighted in red circles are the locations where the nodes have built up. This build up did not cause any issue with the running on the paper machine during the short machine run. However if this process where to be scaled up a need for removing the nodes would be necessary to eliminate build up and possible operational difficulties and equipment mail function.

Some wrinkling was observed on the dry end of the machine. This is not necessarily isolated to the properties of the straw as it may have been associated to the straw being under dried. Changes were made to decrease the moisture content. A final moisture content of 82% was achieved after the couch roll of the Fourdrinier section, 72% moisture content after the press section, and 35% for the straw art paper was the result, due to its high basis weight and operational difficulties in the forming and the dryer section. Moisture content was measured according to TAPPI test method T412 om-06.
Paper testing results of the art paper production run on the 12-inch laboratory fourdrinier paper machine includes (i) 90% straw and 10% NBSK pulp and no calendaring (ii) 85% straw and 15% NBSK pulp and no calendaring, (iii) 85% straw and 15% NBSK pulp and calendaring at a pressure of 20 psi (137895 Pa), and (iv) 85% straw and 15% NBSK pulp and calendaring at a pressure of 30 psi (206842 Pa).

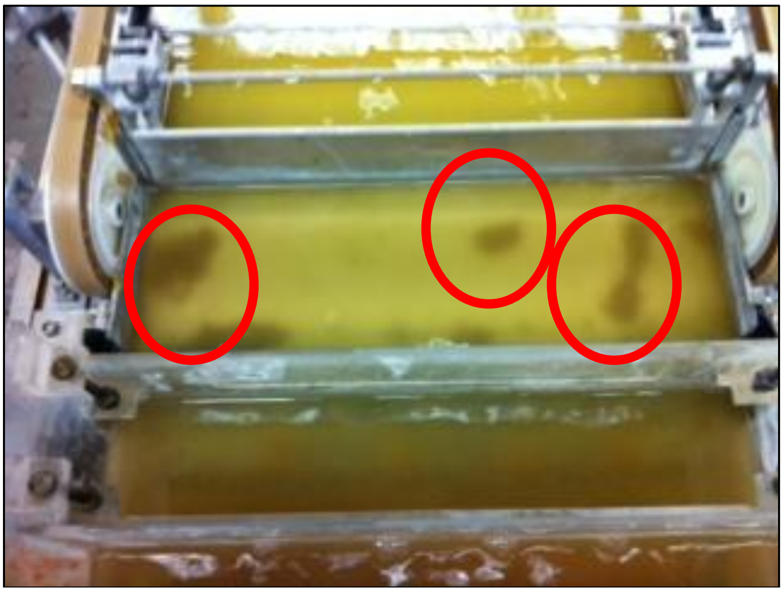

**Fig. 7. Nods build up in headbox**

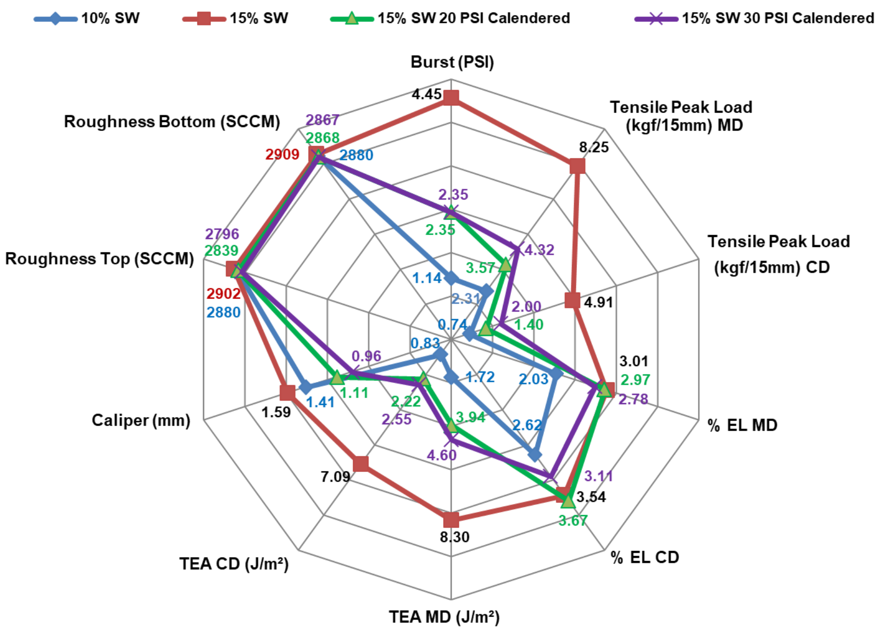


**Fig. 8. Wheat straw art paper unconditioned**

### 3.7.1 Test Results Unconditioned

Lab testing was conducted immediately following the web reaching the reel and prior to the paper being conditioned at a temperature of 23°C and a relative humidity of 50%. The produced straw art paper after the run had a moisture content of 35% due to its high basis weight and operational difficulties removing the moisture of the formed straw art paper sheet in the press and dryer section.

As shown in Fig. 8. calendaring had a significant effect on Burst, Tensile Peak Load and TEA and Caliper at this state of high moisture content.

The 10% and 15% NBSK containing wheat straw paper grade had a caliper of 1410 µm and 1590 µm respectively. Whereas the calendared wheat straw art paper with 15% softwood content and an calendaring pressure of 20 psi (137895 Pa) and 30 psi (206842 Pa) had a caliper of 1110 µm and 960 µm respectively.

The burst load  measured in psi for 10% and 15% NBSK containing wheat straw paper grade was at 1.14 and 4.45 giving the paper with a higher softwood content an almost 4 times high burst load., whereas the calendared paper had a burst pressure of 2.35 for both pressure settings of  20 psi (137895 Pa)  and 30 psi (206842 Pa).

The tensile peak load measured in kilogram-force (kgf) per 15mm wide testing strip for the Machine Direction (MD) and Cross Machine Direction (MD/CD) for 10% and 15% NBSK containing wheat straw paper grade was at 2.31/8.25 and 0.74/4.91 respectively showing that the higher softwood content results in a 3.57 and 6.63 times higher tensile peak load for the MD and CD direction. The tensile peak load for the 15%NBSK pulp containing wheat straw art paper, calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa) showed similar values for the MD/CD direction at 3.57/1.40 and 4.32/2.00.

The Elongation (EL) in % revealed that the 10% NBSK pulp containing wheat straw art paper had a 2.02% and 2.62% elongation for the MD and CD direction. The EL of the 15% NBSK pulp containing wheat straw art paper without calendaring and calendered with 20 psi (137895 Pa)  and 30 psi (206842 Pa) was at 3.01%, 2.97% and 2.78% for the MD direction and 3.54%, 3.67%  and 3.11% for the CD direction.

The Tensil Energy Absorption (TEA) measured in J/m² showed similar results as the tensile peak load. The MD/CD for 10% and 15% NBSK containing wheat straw paper grade was at 1.72/0.83 and 8.30/7.09 respectively showing that the higher softwood content results in a 4.82 and 8.54 TEA increase for the MD and CD direction. The TEA for the 15%NBSK pulp containing wheat straw art paper, calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa) showed similar values for the MD/CD direction at 3.94/2.22 and 4.60/2.55.

The average roughness of the wheat straw art paper for the 10% and 15% NBSK pulp was 2863 ml and 2902 ml for the top and 2880 ml and 2909 ml for the bottom, whereas the calendared 15% NBSK pulp containing paper at a pressure of 20 psi (137895 Pa) and 30 psi (206842 Pa) had a roughness of 2839 ml and 2796 ml for the top and 2868 ml and 2867 ml for the bottom respectively.

The optical properties achieved for the manufactured straw art paper straw  was 22.74% for the ISO brightness and a colour value according to the ISO 11476 method for L*, a*, b*. at 69.49, 2.02, and 15.47 respectively. The opacity was at 100% due to the high caliper of the wheat straw art paper.

### 3.7.2 Test Results Conditioned

Lab testing was conducted after the selected wheat straw art paper specimens were conditioned for several days at a temperature of 23°C and a relative humidity of 50% according to T402 [30].  The final moisture content of the conditioned paper was 93% and the testing results shown in Fig. 8. Are quite similar to that of the unconditioned conditioned wheat straw art paper.

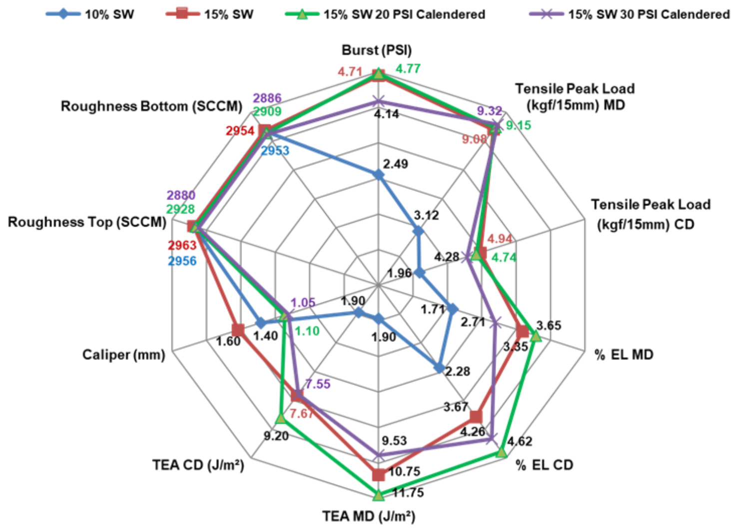


**Fig. 9. Wheat straw art paper conditioned**

As shown in Fig. 9. Calendaring had a significant effect on Burst, Tensile Peak Load and TEA and Caliper of the wheat straw paper as it had for the unconditioned paper specimens.

The 10% and 15% NBSK containing wheat straw paper grade had a caliper of 1370 µm and 1640 µm respectively. Whereas the calendared wheat straw art paper with 15% softwood content and an calendaring pressure of 20 psi (137895 Pa) and 30 psi (206842 Pa) had a caliper of 1090 µm and 1050 µm respectively.

The burst load measured in psi for 10% and 15% NBSK containing wheat straw paper grade was at 2.49 and 4.71 giving the paper with a higher softwood content an almost 1.89 times high burst load, whereas the calendared paper had a burst pressure of 4.77 and 4.14 for 20 psi (137895 Pa) and 30 psi (206842 Pa) respectively.

The tensile peak load measured in kilogram-force (kgf) per 15mm wide testing strip for the MD/CD direction for 10% and 15% NBSK containing wheat straw paper grade was at 4.08/1.96 and 9.08/4.94 respectively showing that the higher softwood content results in a 2.91 and 2.52 times higher tensile peak load for the MD and CD direction. The tensile peak load for the 15%NBSK pulp containing wheat straw art paper, calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa) showed similar values for the MD/CD direction at 9.15/4.74 and 9.32/4.28.

The EL in % revealed that the 10% NBSK pulp containing wheat straw art paper had a 1.71% and 2.28% elongation for the MD and CD direction. The EL of the 15% NBSK pulp containing wheat straw art paper without calendaring and calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa) was at 3.35%, 3.65% and 2.71% for the MD direction and 3.67%, 4.62% and 4.26% for the CD direction.

The TEA measured in J/m² showed similar results as the tensile peak load. The MD/CD for 10% and 15% NBSK containing wheat straw paper grade was at 1.87/1.87 and 10.66/7.66 respectively showing that the higher softwood content results in a 5.70 and 4.09 increase in TEA for the MD and CD direction. The TEA for the 15% NBSK pulp containing wheat straw art paper, calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa), showed similar values for the MD/CD direction at 11.75/9.20 and 9.53/7.55.

The average roughness of the wheat straw art paper for the 10% and 15% NBSK pulp was 2956 ml and 2963 ml for the top and 2953 ml and 2954 ml for the bottom, whereas the calendared 15% NBSK pulp containing paper at a pressure of 20 psi (137895 Pa) and 30 psi (206842 Pa) had a roughness of 2928 ml and 2909 ml for the top and 2880 ml and 2886 ml for the bottom respectively.

The optical properties achieved for the manufactured straw art paper straw was 22.74% for the ISO brightness and a colour value according to the ISO 11476 method for L*, a*, b*. at 69.49, 2.02, and 15.47 respectively. The opacity was at 100% due to the high caliper of the wheat straw art paper.

## 4. CONCLUSION

The presented research project describes the development of a wheat straw art paper product applicable for artistic water color, oil, and encaustic (wax) painting applications. The development included laboratory handsheet development and 12-inch (304 mm) wide laboratory scale paper machine operated at a speed of 3.76 ft/min (1.14 m/min).

The final wheat straw art paper had a moisture content of 93%, basis weight of 350 g/m² and caliper of 1370 µm for a 10% NBSK content, 1640 µm for a 15% NBSK content, and a caliper of 1090 µm and 1050 µm for an calendaring pressure of 20 psi (137895 Pa) and 30 psi (206842 Pa) respectively.

The burst load measured in psi for 10% and 15% NBSK containing wheat straw art paper grade was at 2.49 and 4.71. Calendaring resulted in a bust pressure of 4.77 and 4.14 for 20 psi (137895 Pa) and 30 psi (206842 Pa) respectively.

The tensile peak load measured in kilogram-force (kgf) per 15mm wide testing strip for the MD/CD direction for 10% and 15% NBSK containing wheat straw paper grade was at 4.08/1.96 and 9.08/4.94. The tensile peak load for the 15%NBSK after calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa) was for the MD/CD direction at 9.15/4.74 and 9.32/4.28.

The EL in % revealed that the 10% NBSK pulp containing wheat straw art paper had a 1.71% and 2.28% elongation for the MD and CD direction. The EL of the 15% NBSK pulp containing wheat straw art paper without calendaring and calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa) was at 3.35%, 3.65% and 2.71% for the MD direction and 3.67%, 4.62% and 4.26% for the CD direction.

The TEA measured in J/m² showed similar results as the tensile peak load. The MD/CD for 10% and 15% NBSK containing wheat straw paper grade was at 1.87/1.87 and 10.66/7.66 respectively showing that the higher softwood content results in a 5.70 and 4.09 increase in TEA for the MD and CD direction. The TEA for the 15% NBSK pulp containing wheat straw art paper, calendared with 20 psi (137895 Pa) and 30 psi (206842 Pa) for the MD/CD direction was measured at 11.75/9.20 and 9.53/7.55.

The average roughness of the wheat straw art paper for the 10% and 15% NBSK pulp was 2956 ml and 2963 ml for the top and 2953 ml and 2954 ml for the bottom The calendared 15% NBSK pulp containing wheat straw art paper at a pressure of 20 psi (137895 Pa) and 30 psi (206842 Pa) had a roughness of 2928 ml and 2909 ml for the top and 2880 ml and 2886 ml for the bottom respectively.

The ISO brightness and opacity of the yellowish wheat straw art paper was at 22.74% and 100.00%, The ISO color value was for the L*, a*, b* Hunter color scale 69.46%, 02.02, and 15.47 respectively.
The finished art paper product met the expectations by the artists. The paper was used for several encaustic art studio projects.

It is recommended that the wheat straw based art paper is further developed so I can be produced on a commercial scale paper machine.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Tschudin PF. Vom Tapa-Kofer zur Papiermaschine: Technikgeschichte der besonderen Art“, Wochenblatt für Papierfabrikation. 1999;23(24):1541-1545.
2. Doelle K. Lime in Papermaking – A Historic Review Paper. In: Thompson M.L., Brisch J.H., editors, Lime: Building on the 100-Year Legacy of The ASTM Committee C07American, Society for Testing and Materials (ASTM), ASTM International STP 1557, October. 2012;178–195.
3. Voith Paper. Hainan PM2 – The largest paper machine in the world. Twogether Paper Technology Journal ;2010.
4. Paper Age. Papierfabrik Palm Successfully Commissions New Containerboard Machine, PM5, in Aalen, Germany. Retrieved;2021.
Available:https://www.paperage.com/2021news/07_09_2021palm_startsup_pm5.html
5. Doelle K, Amaya JJ. Application of calcium carbonate for uncoated digital printing paper from 100% eucalyptus pulp. Tappi Journal. 2012;11(1):41-49.
6. Hubbe MA, Rosencrance S. Advances in Papermaking Wet End Chemistry Application Technologies. Tappi Press; 2018.
7. Dahl CF. Process of Manufacturing Cellulose from Wood, US Patent. 1884;296:935.
8. Smook GA. Handbook for pulp & paper technologists. AW Angus Wilde, Vancouver; 2002.
9. Dölle K, Honig A. Laboratory Bleaching System for Oxygen and Ozone Bleaching. Advances Asian Journal of Chemical Science (AJOCS). 2018;4(2):1-12.
10. United States Department of Agriculture (USDA). Wheat Crops. Accessed ;2021.
Available:https://www.ers.usda.gov/topics/crops/wheat/
11. Tridge. Global Sourcing Hub for Food & Agriculture. Accessed;2021.
Available:https://www.tridge.com/intelligences/wheat-straw/export
12. Zhang R, Jenkins BM. Commercial Uses of Straw. Agricultural Mechanization and Automation. 2004;(2):308-341. Accessed 29 December, 2021.
Available:https://www.eolss.net/sample-chapters/c10/E5-11-05-04.pdf
13. Triplepundit. A New Use for Wheat Straw in North America’s First Tree-Free Paper Pulp Mill. Accessed;2021.
Available:https://www.triplepundit.com/story/2019/new-use-wheat-straw-north-americas-first-tree-free-paper-pulp-mill/85686
14. Columbia Pulp. North America’s First Tree-Free Pulp Mill. Accessed;2021.
Available:https://columbiapulp.com/
15. Step Forward Paper. About Us. Accessed;2021.
Available:http://stepforwardpaper.com/about-us/

16. Shandong Tranlin Group. Retrieved 12/10/2021. Available:http://en.tranlin.cn/
17. Guo S, Zhan H, Zhang C, Fu S, Heijnesson-Hultén A, Basta J, Greschik T. Pulp and Fiber Characterization of Wheat Straw and Eucalyptus Pulps – A Comparison. BioResources. 2009;4(3);1006-1016.
18. Sarkhosh Rahmani F, Talaeipour M. Soda-AQ pulping of wheat straw and its blending effect on Old Corrugated Cardboard (OCC) pulp. Tappsa Journal. 2009;35-39.
19. Zhinan F, Raimo A. Soda-AQ pulping of wheat straw. Appita Journal. 2001;54:217-220.
20. Hedjazi A, Kordsachia O, Patt R, Latibari AJ, Tschirner U. Alkaline sulfite–anthraquinone (AS/AQ) pulping of wheat straw and totally chlorine free (TCF) bleaching of pulps. Industrial Crops and Products. 2009;29(1):27-36.
21. Dölle K, Parsons E, Konecny J. Application of Cationic tapioca to Unmodified Pearl Corn Starch – A Papermaking Handsheet Study. Journal of Engineering Research and Reports. 2020;9(4):1-7.
22. Dölle K, Sonntag J, Fischer K, Dominesey T. Improvement of Fiber Fines Retention and Mechanical Properties of Board Paper Using Corn and Tapioca Starch - A Handsheet Study. Journal of Engineering Research and Reports. 2021:20(1):39-50.
23. TAPPI T 200 sp-06 Laboratory beating of pulp (Valley beater method)
24. TAPPI T 205 sp-12. Forming handsheets for physical tests of pulp.
25. TAPPI T 220 sp10. Physical testing of pulp handsheets.
26. TAPPI T 227 om-09. Freeness of pulp (Canadian standard method).
27. TAPPI T 240 om-07 “Consistency (concentration) of pulp suspensions
28. TAPPI method T231 cm-07, “Zero-span breaking strength of pulp (dry zero-span tensile)
29. Screening of pulp was performed in accordance to T 274 sp-08, “Laboratory screening of pulp (Master Screen-type instrument) [20], the instrument used was a Valley type Screen with a 350 µm screen plate and a Voith Valley screen with 150µm screen plate.
30. TAPPI T 402 sp-13. Standard conditioning and testing atmospheres for paper, board, pulp handsheets.
31. TAPPI T 403 om-02, “Bursting Strength of Paper”.
32. TAPPI T 410 om-08. Grammage of Paper and Paperboard (weight per unit area).
33. TAPPI T 411 om-10. Thickness (caliper) of paper, paperboard, and combined board.
34. TAPPI T 412 om-06. Moisture in pulp, paper and paperboard.
35. TAPPI T494 om-06 Tensile properties of paper and paperboard (using constant rate of elongation apparatus).
36. TAPPI T 538 om-08. Roughness of Paper and Paperboard (Sheffield method).
37. ISO 2470 “Paper, board and pulps - Measurement of diffuse blue reflectance factor – Part 1: Indoor daylight conditions (ISO Brightness).
38. ISO 2471:2008 Paper and Board: Determination of Opacity (Paper Backing) – Diffuse Reflectance Method.
39. ISO 11476:2016 Paper and Board – determination of CIE Whiteness, C/2° (Indoor Illumination Conditions).
40. Dölle K, Rainville H. Art paper for large wood relief block printing – A paper development study. Journal of Engineering Research and Reports (JERR). 2021;21(7):1-18.



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