Journal of Engineering Research and Reports

Volume 26, Issue 6, Page 198-211, 2024; Article no.JERR.117124
ISSN: 2582-2926

Sustainable Greeting Card – paper Products Produced on a Laboratory Paper Machine

Klaus Dölle [a,b*], Helga Zoller-Croll [b], David Blazevic [b], Felix Hörl [b], Anna Lexa [b], Fabian Noss [b], Shyam Prasad [b], Gesa Richter [b], Erik Schmeckebier [b], Jack Slavinskas [b] and Matthias Weiß [b]

[a] Department of Chemical Engineering (CHE), College of Environmental Science and Forestry (ESF), State University of New York (SUNY), One Forestry Drive, Syracuse, NY 13210, USA.
[b] Department of Packaging Technology and Paper Process Engineering, University of Applied Sciences Munich, Lothstraβe 34, 80335 Munich, Germany.

Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/jerr/2024/v26i61174

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/117124

Original Research Article

Received: 12/03/2024
Accepted: 16/05/2024
Published: 21/05/2024

ABSTRACT

Paper products have been used for thousands of years for art and communication purposes.
The presented project describes the development of a unique greeting card art paper product, comprised of a card stock with a basis weight of 150 g/m^2 having a purple color tone and inlay paper product with a basis weight of 100 g/m^2. The inlay paper product should have a gras fiber content that is visualized by a tree cut out in the cover paper.

**Corresponding author: Email: kdoelle@esf.edu;*

Cite as: *Dölle, K., Zoller-Croll, H., Blazevic, D., Hörl, F., Lexa, A., Noss, F., Prasad, S., Richter, G., Schmeckebier, E., Slavinskas, J., & Weiß, M. (2024). Sustainable Greeting Card – paper Products Produced on a Laboratory Paper Machine. Journal of Engineering Research and Reports, 26(6), 198–211. https://doi.org/10.9734/jerr/2024/v26i61174*

The inlay paper should be printable with a standard ink-jet printer as well as be able to write on with a fountain pen.
Both paper grades were developed with a hand sheet study and then upscaled to a small 225 mm wide laboratory Fourdrinier paper machine. The produced cover paper and inlay paper had a basis weight of 152.20 g/m² for the cover paper having a purple color tone and 102.64 g/m² for the inlay paper, meeting all mechanical and optical properties as required.
The finished cover and inlay paper product was converted into DIN A5 and DIN A6 card stock, including cutting out the tree image from the cover paper using a laser cutter.

Keywords: Cardstock paper; grass paper; insert paper; laboratory paper machine; papermaking.

1. INTRODUCTION

The invention of paper took place in ancient China during the Eastern Han Dynasty (25-220 CE), at the Imperial Court. The Imperial Court produced every supply needed from daily used items to weapons. During that time Chai Lun, a eunuch, overseeing at that time the workshop is granted the inventorship of paper in 105 CE [1-4]. For hundred s of years the art of papermaking was kept as a secret and was introduced 500 years later in Japan. Approximately another 500 years later it reached Europe and was spread over the rest of the world.

Today paper and board products generally can be described as an orthotropic thin plate with a thickness ranging from 40 µm to over 500 µm and a basis weight from under 15 g/m² to over 500 g/m² [5]. Paper and Board products contain extracted cellulosic fiber material from hardwood (leave) trees, or softwood (needle) trees, and or recycled paper material that contains a mixture of hardwood or softwood cellulosic fibers materials. Based on the various paper and board products additional materials might be added, such as filler materials, color pigments and chemicals, to achieve the specific product requirements [6].

Since the invention of paper, paper products have been used in art applications and to distribute written text. Before the appearance of letter block printing, the only way to transfer written text was to transcribe one document at a time [7].

Each paper grade, especially art papers have their own unique requirements by the artist and or customer. Art paper may have special requirements regarding mechanical integrity, surface topography, optical appearance and printability based on the unique artistic process applied or intended end use of the paper product [8].

Christmas Cards Stock (CCS) for the Sustainable Materials and Product Design departmental use at Hochschule München, University of Applied Sciences falls under the art paper category. It is a specific product produced for a specific intend and a limited small quantity.

The aim of this project was to produce a minimum of 300 cards composed of an 150 g/m² cover paper with a purple color and an 100 g/m² white Inlay Paper with gras fiber content. The cover paper should have a tree image cut into the cover page, allowing to show the specific texture of the inlay papers. The inlay paper should be printable with a standard ink-jet printer as well as writable with a fountain pen for personalized notes.

2. MATERIALS AND METHODS

The following materials and methods were used for the Christmas Card Stock (CCS) Laboratory fourdrinier Paper Machine (LFPM) production run.

2.1 Materials Used

For the CCS a mixture of 80% Hardwood (HW) short fiber and 20% Softwood (SW) long fibers to achieve good run ability and strength during the LPM production run was selected based on previous LPM operational experience. Certified Santa Fe Bleached Eucalyptus Kraft Pulp (BEK) from the cmpc company was selected as HW. As SW Northern Bleached Softwood Kraft (NBSK) pulp from Mercer Inc. was used.

Gras fibers were obtained in pellet form from a nondisclosed manufacturer.

As filler material Ground Calcium Carbonate (GCC), type GL50 manufactured by Omya was used in dry powder form to increase optical properties and to save fiber materials [7,8].

Dyes used for the CCS paper were Cartasol Red 3BFN liq and Cartasol Blue 3RFC liq from ARCHROMA.

As sizing agents Fennosize™ KD 574 MP, an Alkyl Ketene Dimer (AKD) from Kemira was used [8].

Modified corn starch Cationamyl 8425 from AGRANA was used as sizing agent and retention aid to improve fiber and filler retention and increase mechanical paper properties [9,10].

2.2 Testing Methods and Standards

For this research project the following testing methods of the Technical Association of the Pulp and Paper Industry (TAPPI) and the Deutsche Institut for Normung (DIN) Europaeische Norm (EN) International Standardization Organization (ISO) were used:

Beating of pulp (Valley beater method) in accordance with T 200 sp-06 “Laboratory beating of pulp (Valley beater method)” [11].

Handsheets were prepared according to ISO 5269-2:2004, Laborblattbildung für physikalische Prüfungen – Teil 2: Rapid Köthen-Verfahren [12].

Freeness of pulp was measured as Shopper Riegler according to EN ISO 5267-1, Prüfung des Entwässerungsverhalten, Teil 1: Schopper-Riegler-Verfahren [13].

Consistency of the pulp suspensions was measured with TAPPI T240 om-07 “Consistency (concentration) of pulp suspensions” [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 Strength was measured in accordance with DIN EN ISO 2759 Papier - Bestimmung der Berstfestigkeit (German) [16].

Basis weight was measured with DIN EN ISO 536, Papier und Pappe - Bestimmung der flächenbezogenen Masse (German) [17].

Thickness, bulk, and specific volume of the paper was measured with DIN EN ISO 534, Papier und Pappe - Bestimmung der Dicke, der Dichte und des spezifischen Volumens (German) [18].

Moisture content of pulp was determined by DIN EN ISO 287, Papier und Pappe - Bestimmung des Feuchtegehaltes eines Lieferpostens – Wärmeschrankverfahren (German) [19].

Ash in Paper was determined by ISO. ISO 2144, Paper, board and pulps. Determination of residue (ash) [20].

Bending resistance was measured according to DIN 53121, Prüfung von Papier, Karton und Pappe - Bestimmung der Biegesteifigkeit nach der Balkenmethode (German) [21].

Surface roughness of the paper product was measured with DIN 53108, Prüfung von Papier und Pappe - Bestimmung der Rauheit nach Bendtsen (German) [22].

Tensile strength was measured according to DIN EN ISO 1924-2, Papier und Pappe - Bestimmung von Eigenschaften bei Zugbeanspruchung - Teil 2: Verfahren mit konstanter Dehngeschwindigkeit (20 mm/min) (German) [23].

Water Absorption was measured according to DIN EN ISO 535, Papier und Pappe - Bestimmung des Wasserabsorptionsvermögens - Cobb-Verfahren (German) [24].

Color was measured according to DIN 6174, Farbmetrische Bestimmung von Farbmaßzahlen und Farbabständen im angenähert gleichförmigen CIELAB-Farbenraum (German) [25].

According to DIN 476-2:2008-02 Papier-Endformate the size of the paper handsheets were selected (German) [26].

2.3 Additive Preparation

2.3.1 Starch preparation

Starch required for handsheet making and the LFPM run was prepared in water as a solution with 5% solids content using modified corn starch Cationamyl 8425 from AGRANA. To 95The starch was cooked at 90°C to 95°C for 30 minutes in a Kenwood kitchen cooker (Fig. 1) [27]. The cooked starch solution was placed on a laboratory heating plate and kept at 40°C, and constantly stirred to prevent sedimentation till it is used.

2.3.2 AKD Preparation

The sizing agent was prepared using the Kemira FennoSize KD 544M with 23.5% solids content and preparing a solution with water having consistency of 1.0%. After preparation the AKD solution was stirred to prevent sediment till it was used.

Fig. 1. Kenwood kitchen cooker

2.3.3 Dye preparation

The solution of red dye Cartasol Red 3BFN liq, and blue dye Cartasol Blue 3RFC liq were diluted 10-fold for better handling and titrating the dye for handsheet making and dosing the dye during the paper machine run.

2.3.4 Filler preparation

The dry powder Omya GCC GL50 filler material was prepared with water to a solution having a 5.0% solids content. The solution was added the not the fiber suspension to achieve the desired Filler level.

2.4 Art Paper Hansheet Development Procedure

The handsheet development was done by first selecting the fiber material required for the cover and inlay paper product. The fiber mixture selected was 20% SW (NBSK) and 80% HW (BEK), based on previous Laboratory Fourdrinier Paper Machine (LFPM) operational experience. The fiber material for handsheet preparation was prepared according to T-200 sp-06 [12] and refined with a Valley beater to a Schopper Riegler (°SR) value of 28.7, measured according EN ISO 5267-1 [14].

2.5 Laboratory Fourdrinier Paper Machine Run

For upscaling the laboratory tested CSC paper product into continuous production scale, a 22.5 cm wide Laboratory Fourdrinier Paper Machine (LFPM) located at the pilot plant at the Hochschule Muenchen, in the pilot plant of the Sustainable Materials and Product Design (SMPD) Department was used to produce a continuous CSC paper that can be cut into the Christmas cards and insert papers. The set-up of the LFPM system can be described as follow:

2.5.1 Stock preparation and wet end system

The stock preparation of the LFPM, shown in Fig. 2 consists of a 1.3 kW, 15 l low consistency pulper, a 0.5 kW transfer pump, a 10 kW low consistency conical refiner, a 1.75kW progressive displacement pump for circulating he pulp for refining and transferring it to the LFPM wet end system distribution box., Three storage chests with a usable volume of 250 liter, each equipped with a propeller agitator with 1.3 kW can be operated separately or together and serve as refining and LFPM machine chests.

The wet end part of the system consists of a 0.37 kW transfer pump that transfers the fiber suspension from the dilution box to a 0.17 kW progressive displacement feed pump that pumps the fiber suspension to a 1-liter headbox distribution vessel agitated with a 0.17 kW propeller agitator.

Additives for papermaking can be added either in the storage chests and or metered into the pipe prior to the 0.17 kW progressive displacement pump through access manifolds using chemical metering pumps.

From the LFPM fourdrinier table shown in Fig. 4, part of the fiber suspension is recirculated to the 15-liter mix chest containing a 0.15 kW propeller agitator. Excess white water is disposed into the sewer system of the SMPD department pilot plant. The fiber suspension from the mix chest is pumped into the headbox distributer fiber supply pipe after the 0.17 kW progressive displacement feed pump.

2.5.2 225 mm Wide laboratory fourdrinier paper machine

The LFPM shown in Fig. 3 was used to upscale the produced art paper from the handsheet study.

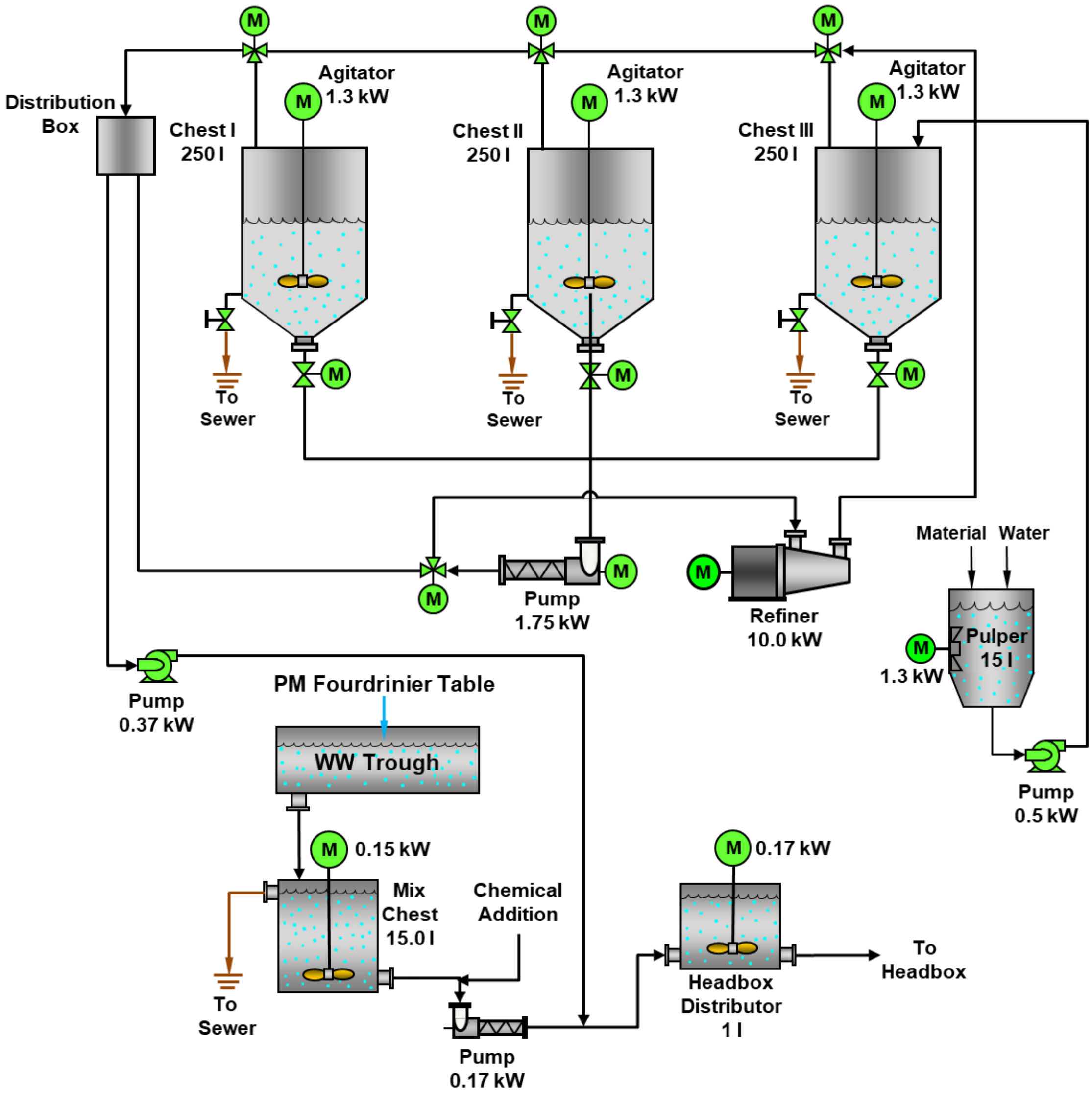


Fig. 2. Laboratory stock preparation system [28]

The LFPM shown in Fig.3, features a 800 mm long Fourdrinier section followed by a 1-nip press section. After the press section a dryer section comprised of a 1[st] and 2[nd] dryer section with 8 (D1-D18) and 4 (D19-D12) electric heated dryer drums. Each dryer drum can be heated to up to 350°C. After the dryer section the produced paper with a basis weight between 20 g/m² and 750 g/m² is reeled into a paper roll at a speed of up to 3.0 m/min.

LFPM wet end has an total installed power of 1.2 kW, whereas the couch roll, the press roll, the press fabric turning roll, dryer can D1 (driving Dryer D2-D4 with gears), Dryer can D5, (driving Dryer D6-D8 with gears) Dryer can D11(driving Dryer D10-D12 with gears), and the real are each driven by a 0.17 kW frequency controlled variable speed drive.

3. RESULTS AND DISCUSSION

All tests for this research and development project were performed in accordance to the TAPPI, DIN, EN, and ISO methods referred to in Section 2.3. All results were in the precision statements for the referenced TAPPI and ISO methods.

3.1 Handsheet Development

For CCS (cover and inlay) we used a fiber mixture that was used for previous LFPM runs, ensuring trouble-free operation. The fiber mixture

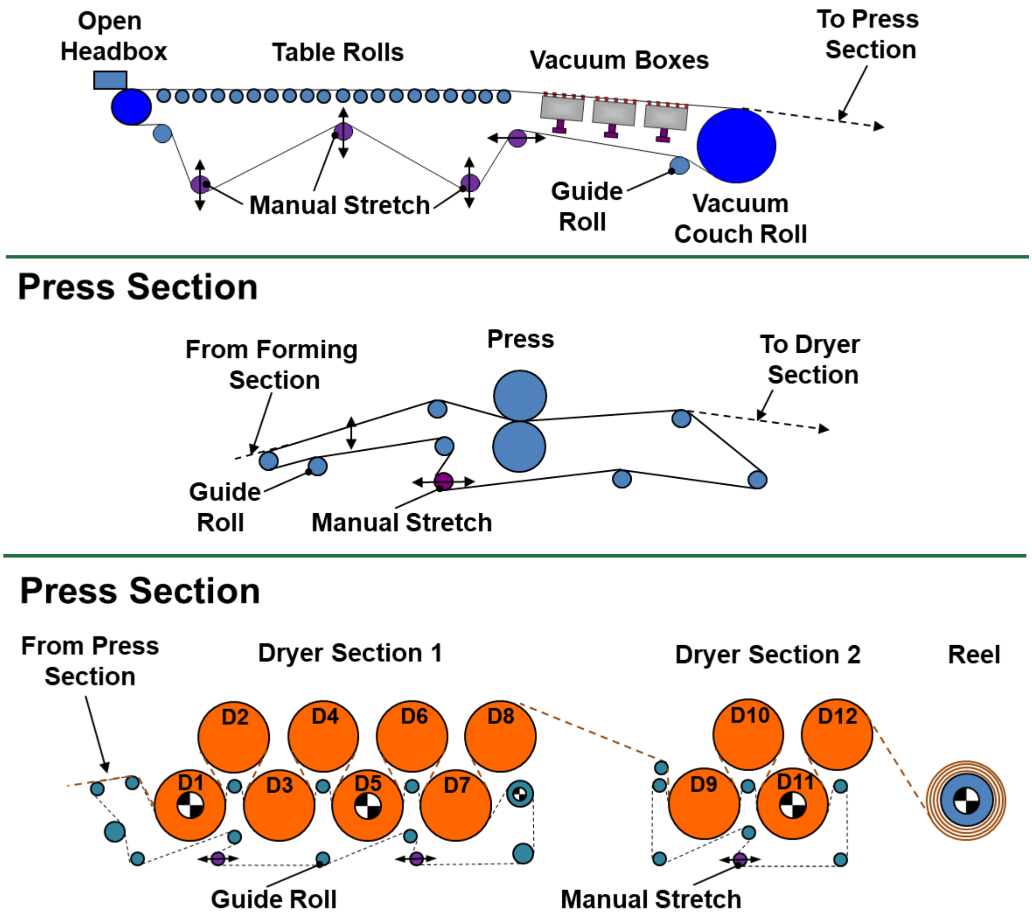


Fig. 3. Laboratory Fourdrinier paper machine [29]

contained 20% SW (NBSK) and 80% HW (BEK). The fiber material for handsheet preparation was prepared according to T-200 sp-06 [11] and refined with a Valley beater to a Schopper Riegler (°SR) value of 28.7, measured according EN ISO 5267-1 [13].

3.1.1 Filler Selection

As filler material Ground Calcium Carbonate (GCC), type GL50 manufactured by Omya was used in dry powder form to increase optical properties, creates a homogeneous paper surface, improves smoothness, printability of the paper product, and to save fiber materials and cost. [4,6,7]. The filler material content was set to be 10% for the cover paper.

For the inlayer paper for the Christmas card, we choose grass fibers and we considered gras fiber to behave like fillers. Grass fibers give the paper special optical properties. The grass fibers are visually very different from conventional fibers. This gives the paper a special haptic and makes it unique.

3.1.2 Chemical addition

In the production of our cover and inlay paper, we use the modified corn starch Agrana Cationamyl 8425. The use of this starch is expected to improve the dry strength of both paper grades. In addition, this starch has a slight cationic character and therefore helps to improve filler retention [9].

To improve the printability and writability properties of the cover and inlayer paper, it is necessary for the paper to have a hydrophobic character. This is achieved using sizing agents. Fennosize KD 574 MP, an alkyl ketene dimer (AKD) from Kemira was chosen as the sizing agent. This product promises to produce a uniform hydrophobization in the neutral paper making processes [10,27].

3.1.3 Color Selection for

The Department of Sustainable Materials and Product Design decided to have a purple color for the cover paper grade.

Laboratory handsheets were manufactured with a dye mixture of red (Cartasol Red 3BFN liq) and blue (Cartasol Blue 3RFC liq) from Kemira as shown in Table 1, using a 10 percent solution of the original dye solution for precise color adjustment.

Table 1. Concentration of dyes

Sample	Red	Blue
1	1%	1%
2	1%	2%
3	1%	3%
4	2%	1%
5	2%	2%
6	3%	3%

The prepared six handsheet color samples, shown in Fig. 4, were based on dye addition in relation to the fiber content of the pulp suspension after starch and filler addition. For dosing the dyes, adjustable laboratory pipettes were used.

The final color selected by the Department of Sustainable Materials and Product Design was Sample 6, with the mixture of three percent red and three percent blue, having a target Color according to DIN 6174 [25] of: L* 16,33; a* = 18,11; b* = -11,8. In Fig. 4 the different color trials can be seen.

3.1.4 Grass Fiber Selection for Inlay Paper

The Department of Sustainable Materials and Product Design decided to have a white color for the inlay paper with gras fibers to give it a sparkly green look. In addition, by adding 10% of recycled gras fibers the inlay papers environmental sustainability is increased.

Three different sets of handsheets were produced with 5%, 7.5% and 10% of gras fiber content based on the HW and SW fiber mix as shown in Fig. 5 to investigate the handsheets texture, visual appearance, and mechanical properties by visual evaluation.

The sheets that had 10% grass fibers showed the best had the most pleasant feel and appearance, most uniform grass fiber distribution, good balance between robustness and longevity and were chosen by the Department of Sustainable Materials and Product Design to be the inlay paper grade.

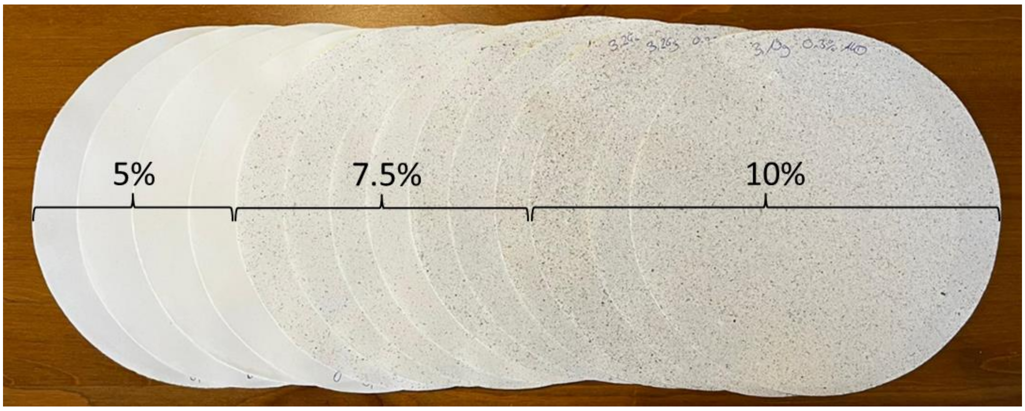
3.1.5 Handsheet Laboratory Testing

In order to define the technical parameters for the LFPM production run, the produced laboratory cover grade and inlay paper handsheets were evaluated for mechanical and physical properties as described in section 2.2 Testing Methods.

Table 2 and Table 3 summarize the results of the mechanical and physical paper properties measurements for the cover paper and inlay paper respectively with the selected additives various paper compositions and additives.

A target basis weight of 150 g/m^2 for the cover grade and 100 g/m^2 for the and inlay paper was chosen and both papers will contain a fiber mixture of a) 20% SW (NBSK) and 80% HW (BEK) refined to SR value of 268.7 at 1.57% solids content.

Fig. 4. Different colors for the cover paper



Fig, 5. Hand sheets with different amounts of grass fibers

Our set goals for the basis weights of both paper types were the easiest to reach. A dry content of 93 - 94% is typical for our laboratory sheet formers. The ash content of 7.65% for the cover paper indicates a 76.5% retention of the fillers used in it on the Rapid Köthen sheet former. It was debated whether a retention aid should be used to retain more of the filler. The main reason for not using retention aid during the handsheet study was the uncertainty about the approximate retention on the paper machine, which could fluctuate based on the operational parameters. If the retention on the LFPM is significantly higher than on the Rapid Köthen sheet former, it could interfere with the starch and or colors during paper manufacturing.

Table 2. Parameters of cover paper handsheets

Parameters	Cover paper
Weight hand sheet [g]	4,60
Basis weight [g/m^2]	148,39
Dry content [%]	93,35
Ash content [%]	7,65
Caliper [µm]	217,00
L*	16,33
a*	18,11
b*	-11,81
Bending stiffness [mN]	2,39
Tensile strength [N]	101.00
Burst [kPa]	526,58
Roughness top [ml/min]	570,15
Roughness bottom [ml/min]	797,46
Cobb without AKD [g/m^2]	260,50
Cobb 0,1% AKD [g/m^2]	30,92
Cobb 0,2% AKD [g/m^2]	23,88

For the grass fibers an ash content of 0% was expected, since neither the starch, cellulose nor the grass fibers should contain any ash. The caliper is similar between both paper types, despite the 50g/m^2 difference in basis weight. The reason for this is the large chunks of grass fibers, which have a significantly higher caliper than the base paper and raise the average caliper almost to the level of the cover paper. The optical properties were only recorded for the cover paper since there were no dyes used for the inlay and the visual evaluation of the paper reveals good results. The strength properties of the inlay are significantly lower than those of the cover paper, mainly because of the lower basis weight and because the grass fibers obviously don’t bond as well as cellulose fibers. The high roughness of the inlay paper comes from the variance in caliper between the grass chunks and the base paper. For the sizing of both papers, the goal was set to a Cobb of 60 to at least 30, to ensure full sizing. Sizing is more important for the inlay paper, because it had to be printed after production, but the cover also had to have some water resistance for eventual printing and converting.

3.2 Paper Machine Runs

The production run of the cover grade and inly grade on the LFPM run focused on achieving the in the laboratory handsheet study achieved mechanical and optical properties having predetermined shade and texture for both grades, while the inlay run emphasized on the the integration of grass fibers for an eco-friendly approach.

3.2.1 Stock preparation

Based on the handsheet development results the produced paper with the LFPM will have a target basis weight of 150 g/m^2 for the cover grade and 100 g/m^2 for the and inlay paper. Both papers will contain a fiber mixture of a) 20% SW (NBSK) and 80% HW (BEK) refined to SR value of 26 at 3% solids content based on dry fiber weight.

Table 3. Parameters of paper Inlay paper handsheets

Parameters	Grass paper
Weight hand sheet [g]	3,04
Basis weight [g/m^2]	101,55
Dry content [%]	93,76
Ash content [%]	0,00
Caliper [µm]	195
L*	90.53
a*	-0.32
b*	-6.44
Bending stiffness [mN]	0,84
Tensile strength [N]	85,9
Burst [kPa]	439,52
Roughness top [ml/min]	3125,62
Roughness bottom [ml/min]	2357,90
Cobb without AKD [g/m^2]	279,43
Cobb 0,1% AKD [g/m^2]	43,45
Cobb 0,2% AKD [g/m^2]	36,56
Cobb 0,3% AKD [g/m^2]	30,34

Prior to refining The SW and HW fiber virgin pulp sheets were ripped into approximately 25 mm x 25 mm squares and then disintegrating with the laboratory pulper, shown in Fig. 2, affiliated with the LFPM stock preparation system at a consistency of five percent in multiple ten-minute runs. Ater refining the pulp mixture were split equally and diluted to 1.0% consistency and stored in chesst number 1 and 2, serving as the machine chest for the cover and inlay run respectively.

The calculated mass of grass fibers was soaked overnight prior in 4 liters of water prior to the LFPM run. Before the LFPM production the soaked grass fibers were added to chest number 2 that served as the machine chest for the inlay paper grade.

3.2.2 Chemical Addition

All of the additives were dosed by using peristaltic pumps at the chemical addition manifold prior to the pump supplying the pulp to the headbox Distributor as shown in Fig. 2. The peristaltic pumps had been calibrated beforehand with the different chemical additives to achieve the right volume flow for each additive during the paper machine run.

The chemical additives were prepared as describe in Section 2.3 and added as follow: a) AKD Fennosize™ KD 574 MP from Kemira based on dry fiber weight at a dosing rate of 12.825 ml/min for the cover grade at a solids content of 0.20%, and at a 0.3% solids content and a flow rate of 12.82 ml/min for the inlay paper grade, b) 1.00% modified corn starch Cationamyl 8425 from AGRANA in a prepared 5% solution was added based on dry fiber weight with a flow rate of 12.825 ml/min. for the cover grade and 8.541 ml/min. for the inlay paper grade, c) a dye mixture of 3.00% red (Cartasol Red 3BFN liq) and 3.00% blue (Cartasol Blue 3RFC liq) both from Kemira diluted 10-fold based on the original solution was added based on dry fiber content at a flow rate of 19.238 ml/min for both colors for the cover paper grade only, d) 15.39 l GCC, GL-50, filler from Omya at a 10% solution based on dry GCC content was added to the machine chest used for the cover paper grade only, and mixed into the pulp, e) 10% grass fibers were added based on the dry fiber amount present in the machine chest used for the inlay paper grade only.

3.2.3 Paper machine parameters

The LFPM was run with a speed of 2m/min for 120 minutes, for both the cover and the inlay grade having a production rate on the reel of 68.00 g/min for the cover grade and 45.00 g/min., yielding 8.10 kg of paper with a moisture content of 5.00% of 8.10 kg for the cover grade and 5.39 kg for the inlay paper grade.

The LFPM was operated at a speed of 2.0 m/min for the start-up and test run as well as for the 2-hour production run for both grades.

The flow rate to the headbox at a consistency of 0.83% for the cover paper grade and 0.45% for the inlay paper at a flow rate of 100.0 l/min with additives added as described in Section 3.2.2.

For both the cover paper and inlay paper the LFPM was operated the same. Vacuum levels for the fourdrinier table were set at 25000 Pa for the suction box vacuum and couch roll vacuum. The fiber flow to the headbox at a consistency of 1% was set at 10.0 l/min to achieve the desired basis weight of 100 g/m² of CSC paper card stock and insert paper product.

The press was operated at 21000 Pa for all CSC paper card stock and insert paper product. The heat for the dryers in dryer section 1 is kept at 60.0°C (300°F) for the 1st dryer (D1), 66.0°C for the 2nd dryer (D2), 83.0°C for the 3rd dryer (D3), 93°C for the 4th dryer (D4), 98.0°C for the 5th dryer (D5), 93.0°C for the 6th dryer (D6), 101.0°C for the 7th dryer (D7), and 99.0°C for the 8th dryer (D8). Dryer section 2 was kept at 101.0°C for the 9th dryer (D19), 106.0°C for the 10th dryer (D10), 1070°C for the 11th dryer (D11), and 106.0°C for the 12th (D12) dryer. The dried CSC paper card stock and insert paper product was rolled up at the winder for further use including physical and optical paper testing as well as converting the card stock and insert paper product into Christmas Cards and inserts.

3.2.4 Paper machine measurements during run

The target basis weight for the cover paper was set to be 150 g/m² ± 5.0% and for the inlay paper 100 g/m² ± 5.0%. After the machine was started up and the paper production parameters adjusted till a basis weight of 151 g/m² for the cover grade at +0.7% above the targeted basis weight, and 102 g/m² for the inlay paper grade at 2.0% above the targeted basis weight was reached.

During the LFPM run the measured machine parameters were a) the headbox consistency, which was 0.83% for the cover grade and o.45% for the inlay paper; b) the white water consistency was 0.33% for both runs, the retention of the LFPM fourdrinier section was 60,2%; c) the white water during the LFPM run for the cover and inlay paper grade run had a had a pH between 7.8 and 8.0 and a temperature between 21.7°C and 22.7°C, the conductivity was between 0.52 µS/cm and 0.54 µS/cm, and a Zeta-Potential between -25.7 mV and 26,7 mV; d) the dryness before and after the press was 18,36% and 47.38% respectively with a dry content of the finished paper before it enters the dryer section of 51.44%, and d) a dry content of 93.35% for the finished cover paper product and 95.36% for the finished inlay paper product.

3.2.5 Finished paper properties

Table 4 shows all measured paper properties of the cover and inlay paper product. The basis weight differs by 2.6% for the cover paper and 1.07% for the inlay paper product, which is caused mainly by the dry content.

The dry content of the LFPM produced paper is 95.36 % for the cover paper and 94.62% for the inlay paper, and therefore 2.2% and 0.91% respectively higher than the dry content of the laboratory hand sheet.

The ash content of the LFPM produced cover paper is 33.3 % lower than that of the hand sheet. This shows that ash retention of the LFPM is poor compared to the Rapid-Köthen handsheet former. Measurements show that the LFPM Fourdrinier section total ash retention was at 60.2%. To increase the ash content in the cover paper the usage of an additional retention agent would allow to improve the ash level in the produced cover paper. The inlay paper was developed with no ash content during the laboratory hansheet study and had no ash present in the LFPM produced inlay paper.

The caliper and specific volume of the LFPM produced paper was 15.70% and 13.00% respectively higher for the cover and inlay paper which caliper, and specific volume increased by 11.79% and 10.41% respectively. The reason for this is that handsheets during the Rapod-Köthen manufacturing are compressed in the dryer, which results in a lower caliper and specific volume.

The high pressure applied during the Rapid-Köthen handsheet manufacturing process influenced as well as the roughness of the laboratory paper handsheet compared the LFPM produced handsheet. In addition, no calendering process was used during the LFPM manufacturing process which would have significantly reduced the roughness of the LFPM produced sheet. The roughness of the of the cover paper handhseet was 570.15 ml/min for the top and 797.46 ml/min for the bottom and 3125.62 ml/min. for the top and 2357.62 ml/min. for the bottom of the inlay handsheet paper product. The LFPM production resulted in a roughness for the cover paper product of 2682.00 ml/min and 26921 ml/min respectively for the top and bottom of the paper sheet. The inlay paper had a roughness of 5853.20 ml/min. and 5500.05 ml/min. for the top and bottom of the inlay paper sheet.

Because the handsheets are more compressed during the Rapid-Köthen handsheet manufacturing process, the individual fibers are closer together and can form more hydrogen bonds. This influences the strength properties together with refining applied to the wooden fibers. The fibers used for manufacturing handsheets were refined with valley beater and the fibers for the LFPM run were refined in a small commercial type of conical refiner. The valley beater fibrillates the fibers more than the conical refiner. As a result, the LFPM produced paper has a higher tensile strength in Machine Direction (MD), in which many of the fibers are aligned during the LFPM manufacturing process. Laboratory Handsheet manufacturing results in a random alignment of fibers during the manufacturing process. The resulting tensile strength is 131.90 N and 98.81 N for the cover and inlay paper respectively compared to the handsheets with a tensile strength of 101.00 N and 85.90 N respectively for the cover and inlay paper.

For both the LFPM manufactured cover and inlay paper the Cross Directional (CD) tensile strength of the LFPM paper was lower at 51.14 N for the cover paper and 39.56 N for the inlay paper.

The breaking length showed the same results. LFPM manufactured cover and inlay paper had a MD breaking length of 5877.80 m and 6542.20 m respectively and an CD breaking length of 2278.90 m and 2625.20 m respectively.

Because the LFPM made paper has a higher specific volume, the bending stiffness in MD direction is higher compared to the laboratory made handsheets. Bending stiffness was 3.59 mN and 1.05 mN for the cover and inlet paper respectively, whereas the CD bending stiffness was lower at 1.92 mN and 0,48 mN for the cover and inlay paper compared to 2.98 mN and 0.48 mN for the laboratory made cover and inlay paper.

Regarding the bursting strength the LFPM paper showed lower values compared to the laboratory made handsheets for the cover and inlay paper. Values were at 348.76 kPa and 240.44 kPa compared to 526,58 kPa and 439.52 kPa for the cover and inlet paper respectively.

Due to the longer maturing time of our LFPM produced paper compared to the laboratory handsheets a 12,4% land 23.5% lower Cobb and therefore better surface sizing was achieved for both the cover and inlay paper product respectively.

The L, a, and b color values of the produced cover paper, including the targeted color value based on the handsheet development of 16.33 for the L-value, 18.11 for the a-value, and -11.81. The 225 mm LFPM production achieved an L, a, b color value of 14.77 which is -9.55% below the target value, 19.65 which is 8.5% above the target value, -11.00 which is 6.77% above the target value respectively.

For the inlay paper the handsheet development had an L-value of 90.53, a-value of -0.32, and a b value of -6.07. The 225 mm LFPM production achieved an L, a, b color value of 83.12 which is -8.18% below the target value, -0.34 which is 6.25% above the target value, and -6.07 which is -6.77% below the target value respectively.

Both color differences of the cover and inlay paper were in the acceptable range.

4. CONVERTING PROCESS

After the LFPM cover and inlay paper production the rolled-up paper was stored for a few days, this resulted in an even more intensive curl than directly after production.

The first step of converting the produced paper into the card cover paper and inlay cover paper was to cut the paper into the right length with a hand guillotine type paper cutter according to DIN 476 [26]. The cover paper was selected to be DIN A5 with a size of 148 mm x 210 mm, and the inlay paper to be DIN A6 with a size of 105 mm x 148 mm. The cover paper was later folded to a DIN A6 format containing the inlay paper.

4.1 Cover and Inlay Paper

After the LFPM produced cover and inlay paper was cut approximately 5 mm bigger than DIN A5 for the cover paper and DIN A6 for the inlay paper because of the curl caused by rolling the paper during manufacturing. To reduce the curl of the cover and inlay paper and to ensure a precise cutting in the last converting step the cut cover and inlay paper was fed as single sheets through a Striegel photo dryer to flatten them as shown in Fig.6a. After the photo dryer flattened the cover and inlay paper, shown in Fig. 6b, both the cover and inlay paper was put into a book press to assure that the cover and inlay paper is flat as possible. The result of this process was very good as shown in Fig. 7.

After 2 days in the book press the cover and inlay paper sheets have been taken out of the press, and a Christmas tree image was cut out of the cover paper to make it into a Christmas card cover. The inlay paper was cut to the final DIN A6 paper sheet size.

Table 4. Quality parameters of the cover and inlay paper

		Cover Paper			Inlay Paper		
Name	**Unit**	**Value Hand-sheet**	**Value Machine produced paper**	**Deviation [%]**	**Value Hand-sheet**	**Value Machine produced paper**	**Deviation [%]**
Basis weight	g/m²	148,4	152,20	2,60	101.55	102,64	1.07
Dry content	%	93,35	95,36	2,20	93,76	94.62	0.91
Ash content	%	7,65	5,10	-33,30	0.0	0.0	0.0
Caliper	µm	217	251	15,70	195	218	11.79
Specific volume	cm³/g	1,46	1,65	13,0	1,92	2.12	10.41
Burst	kPa	526,58	348,76	-33,79	439.52	240.44	-45.29
Tensile strength	N	101,0	MD:131,90 CD: 51,14	30.59 49,36	85.9	MD:98.81 CD: 39.56	15.03 -52.95
Breaking length	m	4625,20	MD: 5877,80 CD: 2278,90	27,80 -50.72	5748,51	MD: 6542.20 CD: 2625.20	13.80 -54.33
Bending strength	mN	2,39	MD: 3,59 CD: 1,92	50.21 -19.67	0.48	MD: 1.05 CD: 0.48	212.50 0.00
Roughness top	ml/min	570,15	2684.00	470.75	3125.62	5853.20	87.27
Roughness bottom	ml/min	797,46	2691.00	337.44	2357.62	5500.05	133.29
Cobb60	g/m²	23,88	20,92	-12,4	30.34	23.21	-12,4
L*	-	16,33	14,77	-9,55	90.53	83.12	-8.18
a*	-	18,11	19,65	8,50	-0.32	-0.34	6.25
b*	-	-11,81	-11,00	6,77	-6.44	- 6.07	6,10

Fig. 6. Cover paper a) in the photo dryer, b) Cover paper after photo dryer

Fig. 7. Final cover paper after book press

Fig. 8. Final assembled christmas card

4.2 Laser Cutting of Cover Paper

Once the cover paper was cut to DIN A5 it was ready for the laser cutter. The Laser cutter used was a Speedy 2000 from Trotec. The program used was the new Ruby program from Trotec which works with files in the Adobe Illustrator format or simple pdf files. Per card it took around 6 seconds to cut the Christmas tree image out of the card. Every card was done separately. To ensure proper folding the card was directly creased by hand and folded after laser cutting. After folding the cards were cut into the final DIN A5 format to ensure a perfectly cut (right angle) for the finished Christmas Card cover.

4.3 Final Christmas Card

300 Christmas cards were produced and assembled consisting of a purple cover and white inlay paper. Fig. 8 shows the finished Christmas card with its distinct look of the gras fiber inlay paper through the cut-out Christmas tree, giving the card through the cut out a distinctive Christmas tree like look.

6. CONCLUSION

The aim of the project was to produce CCS-paper for the department of Sustainable Materials and Product Design use at Hochschule München, University of Applied Sciences. The aim was to produce a minimum of 300 cards with an basis weight of 150 g/m^2 for the cover paper having a purple color tone and a 100 g/m^2 white Inlay Paper with gras fiber content. The CPS should have a tree cut into the cover page, allowing to show the inlay paper. The inlay paper should be printable with a standard ink-jet printer as well as able to write on with a fountain pen.

Both paper grades were developed with a hand sheet study and then upscaled to a small 225 mm wide laboratory Fourdrinier paper machine. The produced cover paper and inlay paper had a basis weight of 152.20 g/m^2 for the cover paper having a purple color tone and a 102.64 g/m^2 for the inlay paper, meeting all mechanical and optical properties.

The finished cover and inlay paper product was converted into DIN A5 and DIN A6 card stock, including cutting out the Christmas tree from the cover paper using a laser cutter. The produced Christmas cards were used by the Sustainable Materials and Product Design department at Hochschule München.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hunter D. Papermaking the history and technique of an ancient art. Dover Publications Inc., New York; 1978.
2. Müller AJ, Zhong XY.The changing origins of paper – from hand-made to machine made. Voith Sulzer together. 1997;(3):74-8.
3. Tschudin PF. Vom Tapa-Kofer zur Papiermaschine: Technikgeschichte der besonderen Art“, Wochenblatt für Papierfabrikation. 1999;23/24:1541-1545.
4. Doelle K, Amaya JJ. Application of calcium carbonate for uncoated digital printing paper from 100% eucalyptus pulp, TAPPI JOURNAL. 2012;11(1):41-49.

5. Dölle K. Paper for Screen Printing Application – A Paper Development Study", Journal of Engineering Research and Reports (JERR), 2022;21(9):45-63, I
Available:https://doi.org/10.9734/jerr/2021/v21i917490
ISSN-2582-2926
6. Dölle K. In-Situ Precipitated calcium carbonate paper filler material: A Review, Journal of Engineering Research and Reports (JERR). 2022;21(11):38-58.
Available:https://doi.org/10.9734/jerr/2021/v21i1117502
ISSN-2582-2926,
7. 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.
Available:https://doi.org/10.9734/jerr/2021/v21i717475
8. Dölle K, Palmer K, Palumbo N, Neary B, Shick I. Rothwell I. Straw for Art Applications – a Paper Development Study, Journal of Engineering Research and Reports (JERR). 2022;22(1):33-88.
9. Agrana. Cationamyl 8425 Product Data Sheet. Paper Thickness; 2014.
10. Kemira OYJ. Fennosize™ KD 574 MP. Sizing agent for paper and board; 2011.
11. Tappi T 200 sp-06 Laboratory beating of pulp (Valley beater method).
12. ISO 5269-2:2004, Laborblattbildung für physikalische Prüfungen – Teil 2: Rapid Köthen-Verfahren. German.
13. EN ISO 5267-1 Prüfung des Entwässerungsverhalten, Teil 1: Schopper-Riegler-Verfahren. German.
14. TAPPI T 240 om-07 "Consistency (concentration) of pulp suspensions.
15. TAPPI T 402 sp-13. Standard conditioning and testing atmospheres for paper, board, pulp handsheets.
16. DIN EN ISO 2759, Pappe - Bestimmung der Berstfestigkeit. German.
17. DIN EN ISO 536, Papier und Pappe - Bestimmung der flächenbezogenen Masse. German.
18. DIN EN ISO 534, Paper and cardboard - Determination of thickness, density and specific volume.
19. DIN EN ISO 287, Papier und Pappe - Bestimmung des Feuchtegehaltes eines Lieferpostens - Wärmeschrankverfahren. (German)
20. ISO. ISO 2144, Paper, board and pulps. Determination of residue (ash).
21. DIN 53121, Testing of paper, cardboard and cardboard - Determination of bending stiffness using the beam method.
22. DIN 53108, Prüfung von Papier und Pappe - Bestimmung der Rauheit nach Bendtsen. German.
23. DIN EN ISO 1924-2, Papier und Pappe - Bestimmung von Eigenschaften bei Zugbeanspruchung - Teil 2: Verfahren mit konstanter Dehngeschwindigkeit (20 mm/min). German.
24. DIN EN ISO 535, Paper and cardboard - Determination of water absorption capacity - Cobb method. German.
25. DIN 6174, Farbmetrische Bestimmung von Farbmaßzahlen und Farbabständen im angenähert gleichförmigen CIELAB-Farbenraum. German.
26. DIN 476-2:2008-02 Papier-Endformate. German.
27. 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.
28. Dölle K. Laboratory Stock Preparation System. pdf-file.
29. Dölle K. Laboratory fourdrinier paper machine. pdf-file.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/117124