



Spruce Woodmeal for Newsprint Applications: A Handsheet Study

Klaus Dölle^{1*} and Sandro Zier²

¹*Department of Paper and Bioprocess Engineering (PBE), College of Environmental Science and Forestry (ESF), State University of New York (SUNY), One Forestry Drive, Syracuse, NY 13210, USA.*

²*Department of Packaging Technology and Paper Process Engineering, University of Applied Sciences Munich, Lothstraße 34, 80335 Munich, Germany.*

Authors' contributions

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

Article Information

DOI: 10.9734/JERR/2020/v10i117027

Editor(s):

(1) Dr. Anuj Kumar Goel, Professor, CMR Engineering College, Kandlakoya, India.

Reviewers:

(1) Ali İhsan Kaya, Mehmet Akif Ersoy University, Turkey.

(2) Nkemakolam Nwachukwu, University of Port Harcourt, Nigeria.

(3) Ahmad Azizi Mossello, Behbahan Khatam Alanbia University of Technology, Iran.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/53847>

Received 10 November 2019

Accepted 16 January 2020

Published 21 January 2020

Original Research Article

ABSTRACT

This study shows that spruce woodmeal can be an alternative cellulosic-based wood additive for newsprint applications. This study used unbleached wood flour produced from Spruce sawdust, ground and sieved to a particle size of 20-40 µm, 40-70 µm, 70-120 µm and 200-500 µm.

Woodmeal was added at levels of 2%, 4%, 6%, 8% and 10% based on oven dry fiber content. The basis weight of the newsprint handsheet manufactured was 80 g/m². The study revealed the following outcomes:

Woodmeal with a particle size distribution of 20-40 µm had the highest density followed by woodmeal with 70–150 µm, 40-70 µm, and 200-500µm. Increasing the woodmeal amount resulted in higher porosity. Woodmeal with a particle size distribution of 20-40 µm gave the lowest porosity and a particle size of 40-70 µm gave the highest porosity.

The Tensile index and burst index show decreasing values for the addition of all woodmeals and particle sizes. Woodmeal with strength additive and a particle size of 20 – 40 µm outperforms the

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

other woodmeal types at additions of 2%, 4%, 6% and 8%. For woodmeal with a particle size of 70–150 µm at an addition of 2% and 4% an increased and similar burst index resulted for the handsheets.

First pass retention and ash retention increased for all wood flours with a maximum at 92% and 81% respectively for the wood flour with a particle size of 40-70 µm.

Keywords: Woodmeal; additive; papermaking; handsheets; paper properties; newsprint; recycled fibers.

1. INTRODUCTION

The paper industry worldwide is increasing their efforts in making paper more sustainable, biodegradable and eco-efficient [1]. In the past decade, the cost for manufacturing paper, board and newsprint paper products has increased dramatically.

For the newsprint sector faces tough competition from electronic media like Internet, communication and information resources. Personal computers, cellular phones, notepads are present in today's life and provide alternatives to newspapers [2]. Just take today a ride in the New York subway. No one is reading a newspaper on the subway anymore. Instead the majority of the travelers use cell phone, I-pad's and similar electronic media to get their information and entertainment. This personal observation concurs with a worldwide decline of newspaper consumption of over 6% as described by Berg and Lingquist [3].

New innovative solutions for the production process are needed to offset cost increases and a decrease in market volume. In addition, tighter environmental regulations demand an increasing use of sustainable chemical and additives. This will result in an increasing use of renewable materials in the future [4] and a constant search for more cost efficient raw materials and additives that can replace the currently used fiber material and at the same time deliver the needed mechanical and physical quality parameters for printability like precipitated calcium carbonate which allows fiber saving and increased optical properties for printing purpose [5,6].

The application of woodmeal, a byproduct from the timber industry, in technical processes is known since the early 1920's when a patent was granted for the use of woodmeal in the production process of phonographic records and other articles [1,7,8]. Woodmeal is produced by grinding sawdust particles to a particle size between 20µm to 500µm with a size ratio of 1:1 [1,9,10]. Today commercial applications of

woodmeal in the area of paper manufacturing are not recorded. Woodmeal is used in the area of Wood Plastic Composites (WPC) and moulding technology applications for articles such as furniture parts, dishes and toys [11,1].

Applications in the manufacturing of paper products have not been explored in detail recently. A handsheet study by Dongmei et al. and Lee et al. [12,13]. He showed that bulk can be improved, and mechanical pulp be replaced using wood powder.

Dölle and Zier investigated woodmeal as an alternative cellulosic-based wood additive for papermaking [14]. Powder manufactured from conifer leaves and agricultural by-products was used in a study by Sung et al. and Park et al. as an organic filler additive in papermaking [15,16].

Woodmeal has not been the focus in recent investigations as an alternative cellulosic-based wood additive for newsprint papermaking applications. This handsheet study compares four commercial varieties of spruce woodmeal at an addition of 2%, 4%, 6%, 8% and 10% as a recycled fiber replacement for the production of newsprint.

2. MATERIALS AND METHODS

This section describes the standardized TAPPI test methods, procedures, and materials used for this study. Repeatability of the results stayed in between the allowable margins of the TAPPI testing standards.

2.1 TAPPI Methods

Handsheets preparation was done according to T 205 sp-06 "Forming handsheets for physical tests of pulp" [17], The ash was measured after T 211 om-02, "Ash in wood, pulp, paper and paperboard: combustion at 525°C [18]. Physical testing of handsheets was performed in accordance to T 220 sp-06, "Physical testing of pulp handsheets" [19], the freeness of pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09 "Freeness of

pulp (Canadian standard method)” [20]. “Forming handsheets for physical tests of pulp”. 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” [21]. Burst Index was measured in accordance with T 403 om-02 :Bursting strength of paper” [22]. Tensile strength was measured in accordance with T404 cm-92, “Tensile breaking strength and elongation of paper and paperboard” [23]. Basis weight was measured with T 410 om-08. “Grammage of Paper and Paperboard (weight per unit area)” [24]. The paper thickness was measured by T 411 om-10 “Thickness (caliper) of paper, paperboard, and combined board” [25]. Moisture content of pulp was determined by T412 om-06 “Moisture in pulp, paper and paperboard” [26]. Tensile strength was performed following T494 om-06, “Tensile properties of paper and paperboard (using constant rate of elongation apparatus)” [27]. The porosity was measured according to T 547 0m-07, “Air permeance of paper and paperboard (Sheffield Method) [28].

2.2 Deviation of Testing Methods

2.2.1 Handsheet preparation

A deviation from the TAPPI test method T205-sp06 was necessary to produce better quality handsheets for paper testing. The pulp suspension, consisting of fiber and WF raw material, was prepared at 1.6% instead of 1.2% Oven Dry (OD) solids content. This change produced handsheets with a basis weight of 80 g/m² instead of 60 g/m².

2.2.2 Handsheet drying

TAPPI T 205 sp-12 requires the handsheets to be fully dried at a Relative Humidity (RH) of 50% and 23°C from the wet state to equilibrium. Since the heating process of the paper is influential to the industrial process, the industrial drying process was replicated by using a Dayton Photo Dryer shown in Fig. 1. a and b for the hand sheets. The target was to get as close as possible to the method of the industrial paper production.

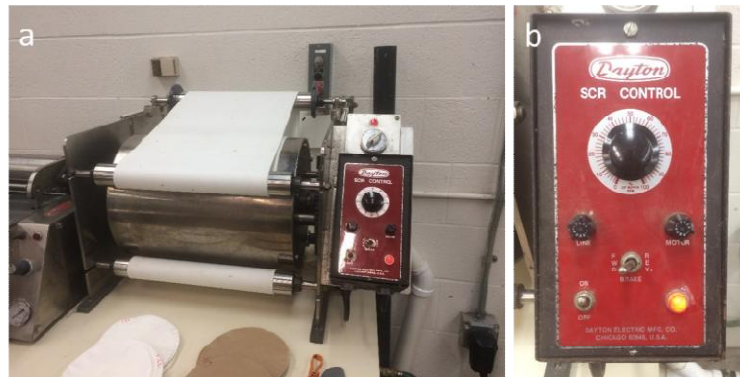


Fig. 1. Dayton photo dryer [xx]

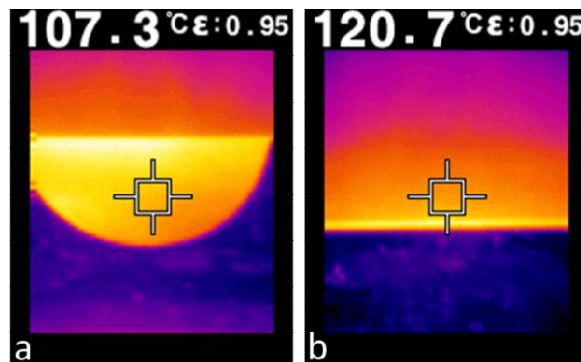


Fig. 2. Drying temperature: a) Handsheet, b) Drying felt/ cylinder [xx]

The Dayton Photo Dryer was used in a way that the handsheets touched the heated drum surface for 1 min and 40 seconds in a covered angle of 270° of the dryer drum (Fig. 1.a). Each handsheet rotates through that procedure 2 times. First time the wire side and the second time the top side of the handsheet was faced to the heated steel cylinder.

The target temperature on the cylinder surface was 120°C. Fig. 2a. shows the temperature of the handsheet at 107°C and Fig. 2b. the temperature of the felt/cylinder at the set temperature of 120°C. The cylinder temperature could not be measured with an infrared camera, due to the shiny surface of the cylinder. To get an accurate temperature reading the surface temperature of the felt on the outlet nip was measured.

2.2.3 Retention of handsheets

The First Pass Retention (FPR) for handsheet made in accordance to T205 sp-06 was calculated based on oven dry mass of the handsheet in gram over the dry mass of fibers in gram in the suspension used to produce the handsheet.

$$\text{First Pass Retention [\%]} = \frac{\text{Handsheet mass [g oven dry]}}{\text{Input Handsheetmaker [g oven dry]}} \cdot 100 \%$$

For the ash retention the same formula was used just only with the ash particle. The ash was measured according to TAPPI T211-om-02 [15].

$$\text{Ash Retention [\%]} = \frac{\text{Handsheet ash mass [g oven dry]}}{\text{Input ash Handsheetmaker [g oven dry]}} \cdot 100 \%$$

2.3 Materials

2.3.1 Raw materials

2.3.1.1 Natural woodmeal

The WF used for this study was obtained from J. Rettenmayer & Söhne GMBH & CO KG (JRS) and made according to the manufacturer from 100% Spruce sawdust, ground and sieved to a particle size of 20 µm – 40µm, 40 µm – 70µm, 70 µm – 120µm, and 200 µm – 500µm respectively.

The chemical composition, metal content, and physical properties of the wood meal is shown in Table 1, Table 2 and Table 3 respectively.

The chemical and physical characteristics from all the wood meals were the same. They were described as beige and cubic. The pH-value of

the suspended wood meal at 10% solids content had a range between pH 4.5 and 6.5. The oxide ash content of the 20 µm – 40µm was 0.8% and for the 40 µm – 70µm, 70 µm – 120 µm and 200 µm – 500 µm 0,8% respectively. The bulk density has an increasing tendency, which is unusual. Normally, the finer particles have less air between the individual particles resulting in a lower volume.

The wood meal particle size distribution based on screen analyses from JRS is shown in Table 4., which shows that at the smaller particle size wood meals have particles present that are at the upper end or even bigger than the main particle size range.

2.3.1.2 Woodmeal with additives

This kind of wood meal is labeled in the following report with the ending “-strength”. The different sizes which were described in 0 2.3.1.1 Natural wood are also valid for these wood meals. According to the manufacturer JRS, the raw material is also spruce sawdust which is ground with the same process as the normal woodmeal. The difference is the novel additive which gets attached to the woodmeal after that process.

2.3.1.3 Woodmeal preparation for handsheet making

The different wood meals were suspended in deionized water at a consistency of 0.3% solids content at 20°C. To prevent the wood meal from separating in the solution, it was continuously stirred without any heat on a magnetic stirring plate.

Table 1. Chemical composition of woodmeal [29]

Type	Proportion
Alpha Cellulose	39,00%
Hemicellulose	26,50%
Lignin	25,70%
Extracts	1,60%
Oxide Ash (850°C, 4h)	0,80%
Loss on drying:	6,40%

Table 2. Metal content of wood flour [29]

Metal	Proportion
Arsenic	0,10 mg/kg
Lead	0,50 mg/kg
Mercury	0,02 mg/kg
Cadmium	0,20 mg/kg

Table 3. Physical properties of wood flour [29]

Property	20 – 40 µm	40 – 70 µm	70 – 150 µm	200 – 500 µm
Characteristics	Beige, cubic			
Average Particle range	20 – 40 µm	40 – 70 µm	70 – 150 µm	200 – 500 µm
pH-Value (10 % Suspension)	4.5 -6.5			
Oxide Ash	0,8%	0,5%	0,5%	0,5
Bulk Density/ Average	180 – 210 g/l 195 g/l	120 – 170 g/l 145 g/l	140- 200 g/l 170 g/l	160- 240 g/l 200 g/l
Water Binding capacity	4,0 g Water / g Cellulose			
Oil binding capacity	2,7 g oil / g Cellulose			

Table 4. Shows the screen analyses [29]

Property	20 – 40 µm	40 – 70 µm	70 – 150 µm	200 – 500 µm
>32 µm		10,0% - 70,0%	max. 95,0%	
>45 µm	Max. 10,0%			
>71 µm		max. 45,0%		
>100 µm	max. 0,5%		max. 45,0%	min. 80,0%
>200 µm		max. 0,5%		
>250 µm			max. 0,5%	20,0% - 45,0%
>400 µm				1,0%

Table 5. Newspaper properties

Type	Value
Bulk [cm ³ /g]	1,3- 1,5
Brightness [%] ISO 2470	58,0
Breaking length MD [m]	5500,0
Roughness Bendtsen [ml/min]	100,0 - 200,0
Color L*; a*; b*	83,0-0,0; 0,5-0,0; 3,5-4,5

2.3.1.4 Newspaper

The newspaper was produced by a state-of-the-art industrial paper making process machine. Rolled and cut from a mother roll to the customers roll via winder. On that positions the sample were taken which were used for this research as raw material. This position was chosen because of the changing of paper property's during the winding process. The newspaper was produced from 100% recycled paper using a two-loop deinking system. The recycled paper came from households which have a percentage of graphical paper and magazines of 80%. The not deinkable portion should be under 1.5% [30]. The newspaper contained 19.4% and a moisture content of 6%. Table 5. Shows the newspaper properties according to the manufacturer.

Table 6 shows the fiber analyses of the prepared pulp for handsheet according to ISO16065-2 [31] using Valmet FS5 Fiber Analyzer.

Table 6. Newspaper fiber analyzation

Type	Value
Average fiber length	1,0 mm
Average fiber width	19,4 µm
Length to diameter ratio	51,5:1,0
Curl	12,2%

The results of the fiber analyzation show that pulp has the same fiber length as a natural hardwood. Beech has for example a fiber length between 0,6 and 1,3 mm and a fiber width between 15-21 µm. The beech length to diameter ratio is 50:1, while our recovery pulp has 51,5:1 [30].

2.4 Image Analyses Wood Meal

Three-Dimensional Scanning Microscope (3DSM) and Scanning Electron Microscope (SEM) was used for an image analyzation of the WF particles.

3. RESULTS AND DISCUSSION

All handsheets were made and tested according to TAPPI standards using WF with a particle size of 20 μm – 40 μm , 40 μm – 70 μm , 70 μm – 120 μm , and 200 μm – 500 μm with and without strength additive. WF was added at levels of 2%, 4%, 6%, 8% and 10% based on OD pulp. The black error bars are indicating the standard deviation based on 10 Measurements.

Fig. 3 shows the density of the newsprint pulp on the y-axes and the additional woodmeal in % on the x-axes. The highest decrease of density based on the original newsprint sample was for the 200 μm - 500 μm woodmeal represented by the yellow line, followed by 70 μm – 150 μm woodmeal represented by the gray line, followed by 40 μm - 70 μm represented by the orange line. The 20 μm - 40 μm woodmeal represented by the blue line had the highest density.

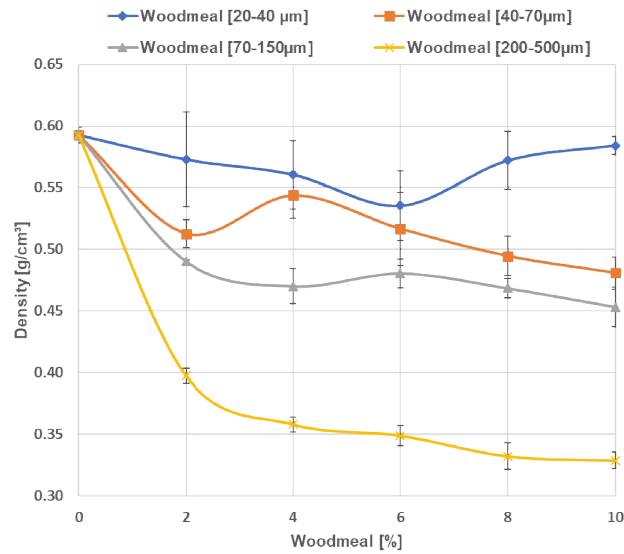


Fig. 3. Newspaper density

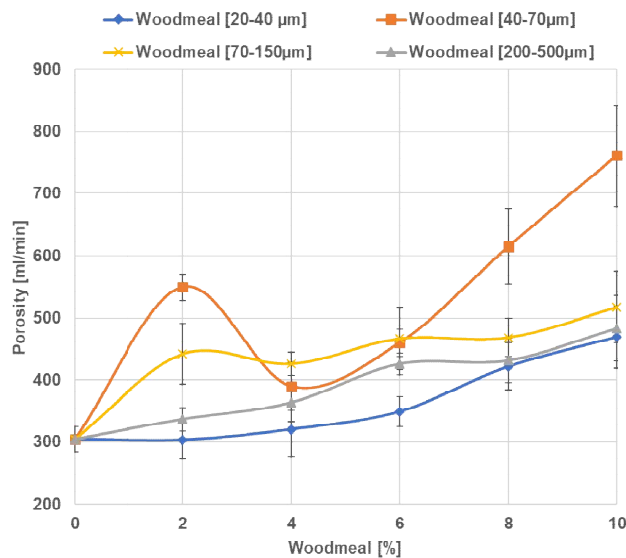


Fig. 4. Newspaper porosity

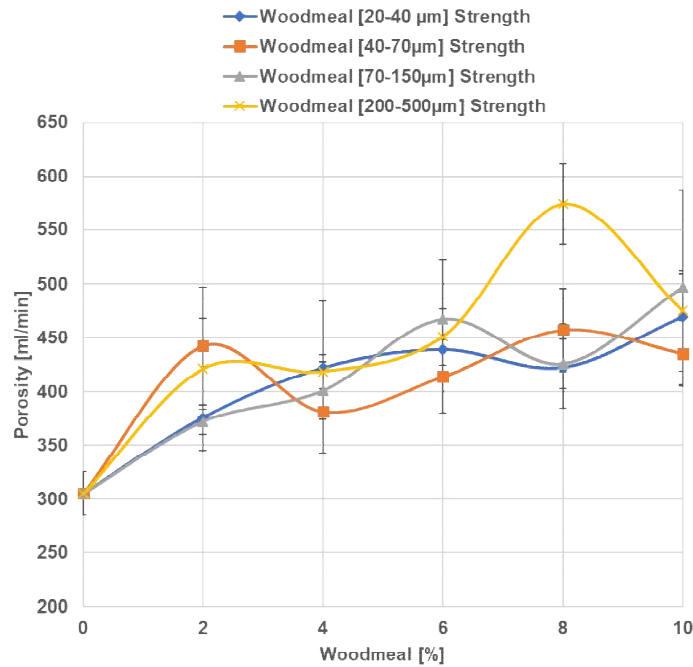


Fig. 5. Newspaper porosity with strength additive

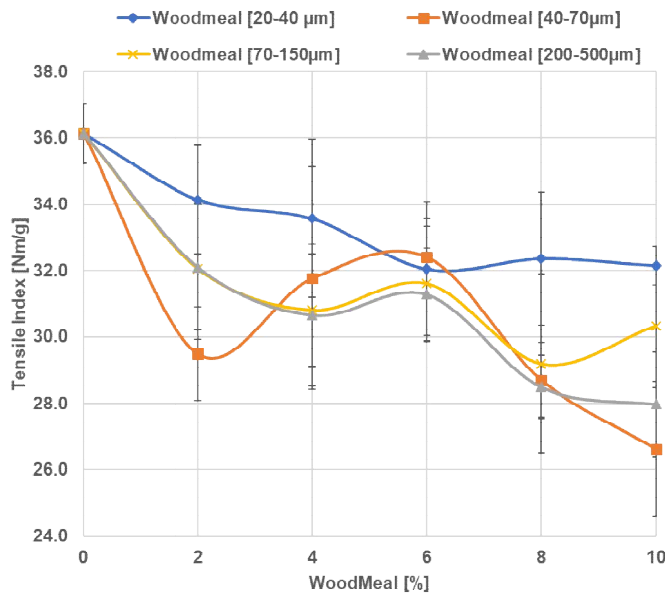


Fig. 6. Newspaper tensile index

The graph in Fig. 4 shows the porosity in ml/min on the y-axis and the additional of woodmeal in % on the x-axis.

The blue graphs show the addition of woodmeal with 20 µm - 40 µm having the lowest porosity

value, followed by the woodmeal with a particle size of 200 µm - 500 µm represented by the gray graph. The orange graph representing the woodmeal with a particle size of 40 µm - 70 µm gave the highest porosity value at 2% and 10% addition. The yellow graph representing the

woodmeal with a particle size of 70 μm – 150 μm resulted in the highest porosity at a 4% and 6% addition.

All graphs show that with a higher addition of woodmeal a higher porosity is achieved. The difference of porosity for the orange graph at the 4% and 6% level can be explained with the sheet making method after TAPPI. If there is a difference in dryness after drying the final handsheet preparation process with a weighted roll might compact the handsheet more, resulting in a lower porosity value.

Fig. 5 shows the newsprint pulp with the so-called strength woodmeal. Overall, the “strength” woodmeal has the same tendencies as the natural woodmeal. In general, it can be stated that with an increasing woodmeal content the porosity also increases due to the larger particle size of the woodmeal compared to the wooden fiber material. Meaning, a void is generated between the fibers by the woodmeal which allows that air passes more easily through the formed handsheet.

The blue line describes the 20 μm - 40 μm woodmeal, while the red line represents the 40 μm – 70 μm woodmeal. The grey and yellow graphs are showing the 70 μm - 150 μm and 200 μm - 500 μm woodmeal respectively. The black error bars are indicating the standard deviation.

Again, the larger difference of porosity for the orange, gray and yellow graph at the 4%, 6%, and 8% level can be explained with the sheet making method after TAPPI. If there is a difference in dryness after drying the final handsheet preparation process with a weighted roll might compact the handsheet more, resulting in a lower porosity value.

Graphs in Fig. 6 show the tensile index in Nm/g on the y-axes and the additional woodmeal in percent on the x-axes.

The blue graph shows the addition of woodmeal with 20 μm - 40 μm , the orange graph with 40 μm - 70 μm , the yellow graph the addition of 70 μm - 150 μm , and the grey graph the addition of 200 μm - 500 μm .

As it can be seen the tensile strength of the paper decreases with the addition of woodmeal. The graphs also show that as bigger the particle size of the woodmeal is as further the strength decreases. Larger particles of Woodmeal will be

not included into the fiber structure of the sheet, and therefore creating a weak spot in the handsheet, resulting is earlier break, then it would be with a more even particle size distribution. They will be more like a foreign particle and will not be combined as well in the fiber structure eliminating hydrogen bonding between the fibers.

Graphs shown in Fig. 7 represent the woodmeal with Strength additive. The woodmeal with a particle size of 20 μm - 40 μm represented by the blue graph outperforms the other woodmeal types, leading to a strength gain for the addition of 2%, 4%, 6% and 8%. Woodmeal having a particle size of 40 μm – 70 μm , 70 μm - 150 μm , and 200 μm – 500 μm is represented by the orange, yellow, and grey graph respectively showed a decrease in tensile index, except for the 2% addition of the 70 μm - 150 μm woodmeal.

Fig. 8 shows the graphs for the burst index in kPam^2/g on the y-axes and the additional woodmeal in % on the x-axes. The blue graph represents the addition of woodmeal with 20 μm - 40 μm , the orange graph with 40 μm - 70 μm , the yellow graph the addition of 70 μm - 150 μm , and the grey graph the addition of 200 μm - 500 μm .

All the graphs show the tendency as for the tensile index. A decreasing bursting strength resulted with increased addition of all woodmeal, except for the 70 μm - 150 μm at addition of 2% and 4% were an increased and similar burst index resulted respectively compared to the handsheet without woodmeal addition.

Woodmeal with strength additive are shown in Fig. 9 for the burst index. in kPam^2/g on the y-axes and the additional woodmeal in % on the x-axes. Woodmeal with strength additive and a particle size of 20 μm - 40 μm , 40 μm - 70 μm , 70 μm - 150 μm , and 200 μm - 500 μm is represented by the blue, orange, yellow, and grey graph respectively. As for the tensile index, and burst index without strength additive, the strength of the handsheet decreased with increased addition of all woodmeal, except for the woodmeal with a particle size of 20 μm - 40 μm at addition at 2%, 4%, and 6% and the woodmeal with a particle size of 40 μm - 70 μm at an addition of 4%. For these addition rate an increased and similar burst index resulted compared to the handsheet without woodmeal addition.

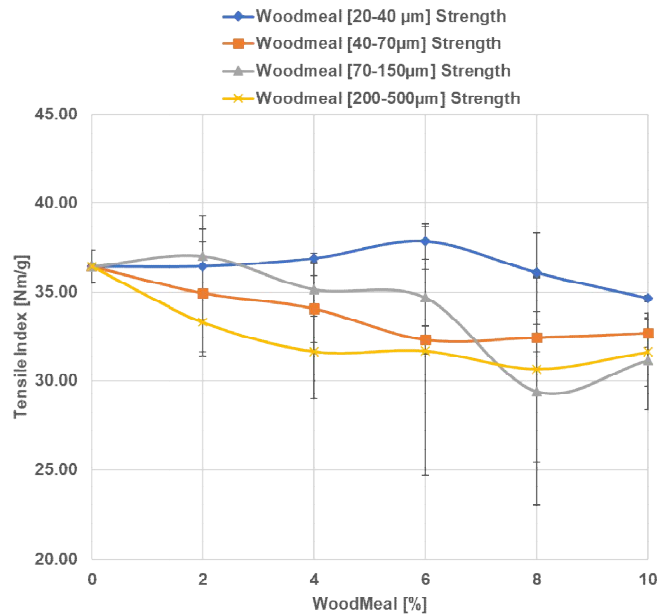


Fig. 7. Newspaper tensile index with strength additive

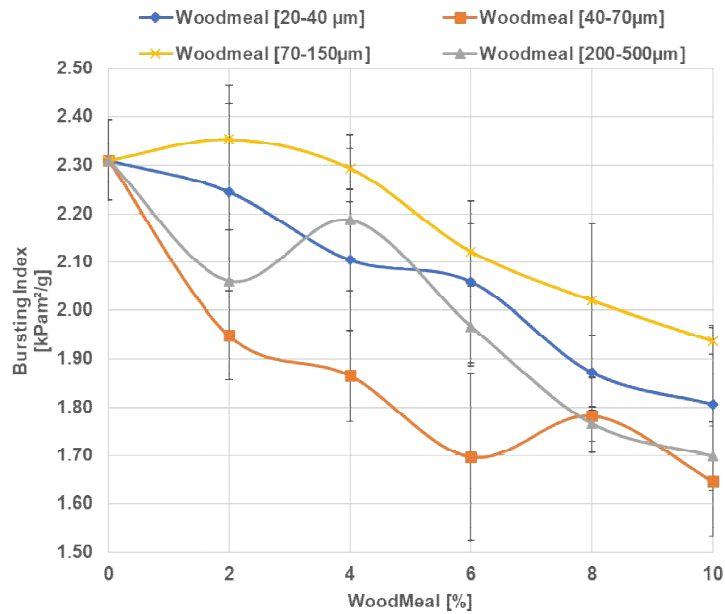


Fig. 8. Newspaper burst index

The reason for a decreasing burst index for regular and woodmeal with strength additive can be explained the same as the decrease in tensile index. It can be expected that the largest woodmeal particles have the largest decrease of strength. All wood meal graphs are close together, which means that the differences are

through measurement inaccuracy. Another reason as described in the above is that the particle size distribution is relatively wide, causing problems, because one bigger particle is enough to create a weak spot in the paper, resulting in early bursts or rupture, as it would be with a more even particle size distribution.

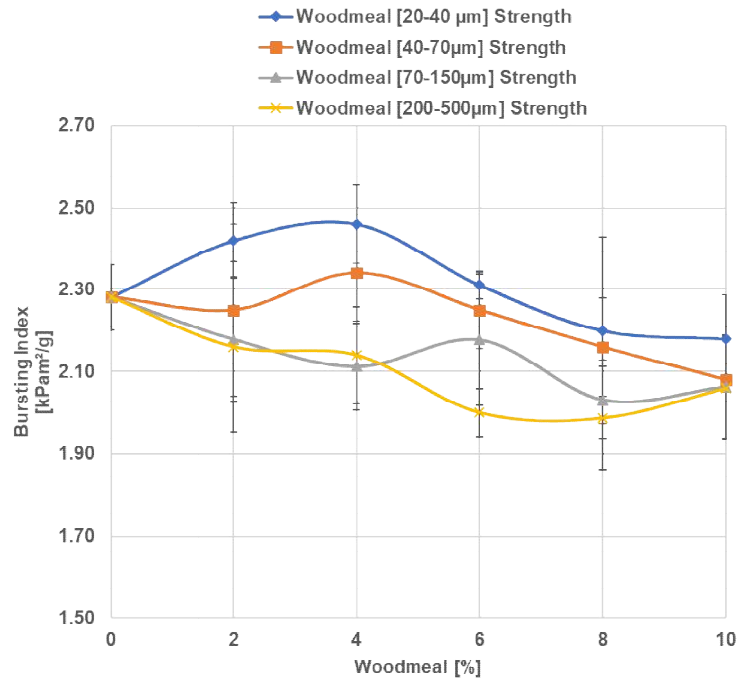


Fig. 9. Newspaper burst index with strength additive

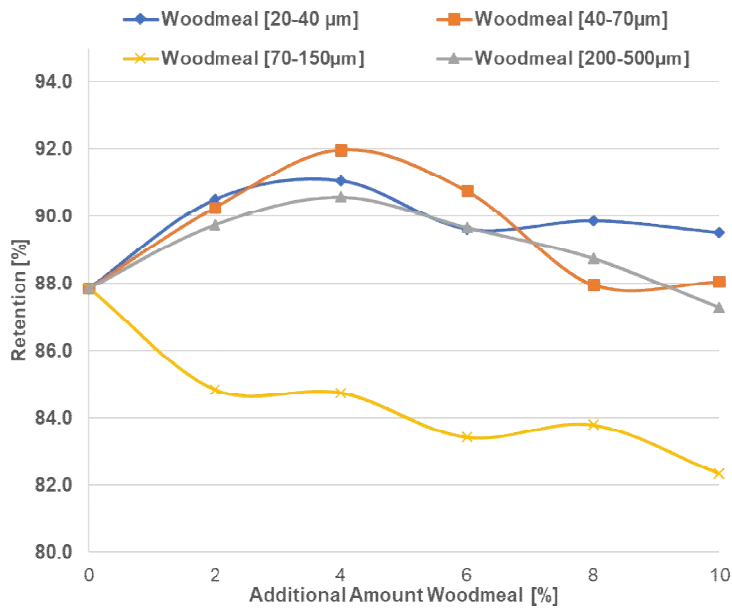


Fig. 10. Newspaper first pass retention

Fig. 10 shows the first pass retention in % on the y-axis and the additional woodmeal in % on the x-axis, where the blue graph represents the 20 µm - 40 µm woodmeal. The 40 µm - 70µm woodmeal is shown with the orange graph. The grey and yellow graphs are showing the 70 µm - 150 and 200 µm - 500 µm woodmeal respectively.

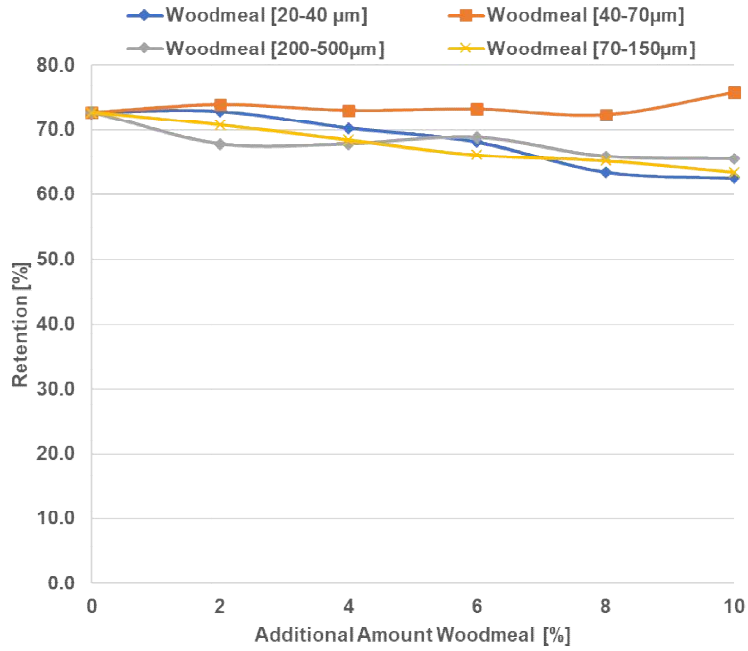


Fig. 11. Newspaper ash retention

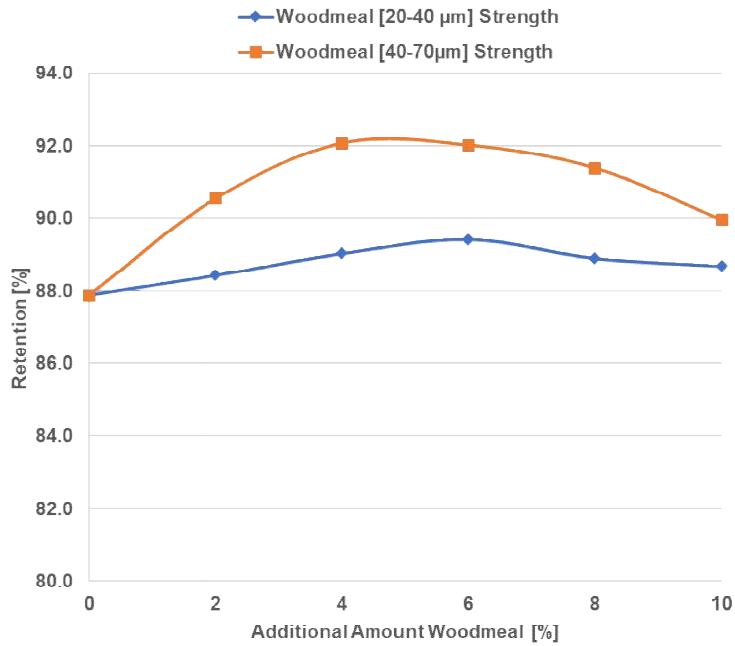


Fig. 12. Newspaper first pass retention with strength additive

The blue, orange, and grey graphs show an increase of the first pass retention to a maximum for a 4% additional woodmeal. The 40 µm - 70 µm woodmeal represented by the orange graph shows the highest maximum with a first pass retention of nearly 92%, a 4% increase in retention for all additions. The 20 µm - 40 µm woodmeal represented by the blue graph shows a decrease of the first pass retention for all additions.

comparison to the newspaper handsheet without woodmeal.

Fig. 11 shows for the same conditions the ash retention. Here it can be seen that the ash retention stays nearly at the same level or decreases slightly.

If the percentage of wood meal increases, the total amount of ash will decrease because there is a lower percentage of newspaper pulp. Less newspaper pulp means that there is less filler put into the hand sheet maker. This makes it more likely that it fell through the wire before a fiber mat was built as a second filter layer on top of the wire of the handsheet former.

The graph in Fig. 12 shows an evaluation of the first pass retention of the best performing woodmeal with a particle size of the 20 µm - 40 µm and 40 µm - 70µm represented by the orange and blue graph respectively using the woodmeal with high strength additive only. Both woodmeal with strength additive show an increase in first pass retention for the addition of 2%, 4%, 6%, 8% and 10%. However, the woodmeal with a particle size of 40 µm - 70 µm shows a maximum at 4 % addition with a 92%

retention compared to the handsheet without woodmeal addition.

The woodmeal with a particle size of the 20 µm - 40 µm represented by the blue graph shows a constant or slightly increasing retention also with a maximum at 6% having a 89.5% retention value compared to the 88% retention value of the handsheet without woodmeal addition.

The graphs in Fig. 13 shows the ash retention of the best performing woodmeal with a particle size of the 20 µm - 40 µm and 40 µm - 70µm represented by the orange and blue graph respectively using the woodmeal with high strength additive only. Both woodmeal with strength additive show an increase in first pass retention for the addition of 2%, 4%, 6%, 8% and 10%. However, the woodmeal with a particle size of 40 µm - 70 µm shows a maximum at 4 % addition with a 92% retention compared to the handsheet without woodmeal addition.

The woodmeal with a particle size of the 20 µm - 40 µm represented by the blue graph shows a constant or slightly increasing retention also with a maximum at 6% having a 89.5% retention value compared to the 88% retention value of the handsheet without woodmeal addition.

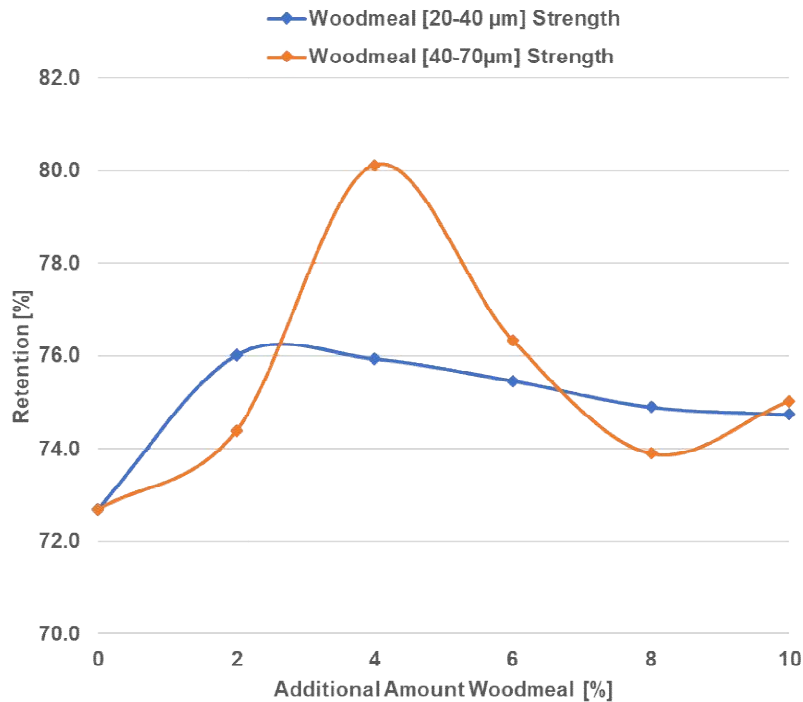


Fig. 13. Newspaper ash retention with strength additive

The woodmeal with a particle size of 40 µm - 70µm has an increase of the ash retention up to a maximum of 81% at 6% addition compared to the 72.5% ash retention at no woodmeal addition. Afterwards it will decrease to 76.5%, 74% and 75.5% at an addition of 6%, 8%, and 10% respectively.

The woodmeal with a particle size of 20-70µm has an increase of the ash retention up to a maximum of 76% at 2% addition compared to the 72.5% ash retention at no woodmeal addition. Afterwards it will decrease and to a 74.5% ash retention at 10% woodmeal addition.

4. CONCLUSION

This 80 g/m² newsprint handsheet study shows that unbleached woodmeal, produced from Spruce sawdust, with a particle size of 20 µm - 40µm, 40 µm - 70µm, 70 µm - 120µm, and 200 µm - 500µm can be considered an alternative cellulosic-based wood additive for newsprint applications at additions of 2%, 4%, 6%, 8% and 10% based on oven dry fiber content.

Woodmeal with a particle size distribution of 20 µm - 40 µm had the highest density followed by woodmeal with 70 µm - 150 µm, 40 µm - 70 µm, and 200 µm - 500µm. Increasing the woodmeal amount resulted in higher porosity.

Woodmeal with a particle size distribution of 20 µm - 40 µm gave the lowest porosity and a particle size of 40 µm - 70 µm gave the highest porosity.

Tensile index and burst index show decreasing values for the addition of all woodmeals and particle sizes. Woodmeal with strength additive and a particle size of 20 µm - 40 µm outperforms the other woodmeal types at additions of 2%, 4%, 6% and 8%. For woodmeal with a particle size of 70 µm -150 µm at an addition of 2% and 4% an increased and similar burst index resulted for the handsheets.

First pass retention and ash retention increased for all wood flours with a maximum at 92% and 81% respectively for the wood flour with a particle size of 40 µm - 70 µm.

ACKNOWLEDGEMENTS

The authors wish to thank the Paper and Bioprocess Engineering Department at the State University of New York, College of

Environmental, Science and Forestry, Syracuse, New York, USA and J. Rettenmaier & Söhne, Rosenberg, Germany for the support for this research project.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Dölle K, Zier S, Lombardi L, Stein T, Winkelbauer S. Spruce Wood Flour for Paper Applications – A Handsheet Study. *Asian Journal of Chemical Sciences*. 2019; 6(1):1-11.
2. Latta GS, Plantinga AJ, Sloggy MR. The effects of internet use on Global Demand for Paper Products, *Journal of Forestry*. 2016; 114(4):433-440.
3. Berg P, Lingquist O. Pulp, paper and packaging in the next decade: transformational Change, McKinsey & Company. 2019;1-15.
4. Lyon SW, Quesada-Pineda HJ, Crawford SD. Reducing electrical consumption in the forest products industry using lean thinking," *BioRes*. 2014;9(1):1373-1386.
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. Dölle K, Baumgartner NF, Goodman A. Kliisiotisoris, hybrid precipitated calcium carbonate containing wood flour for papermaking applications-a comparative handsheet study. *Chemical Science International Journal*. 2019;27(2):1-13.
7. Cunningham JJ. Method for Producing Flour, US Patent No. 1,406,938; 1922.
8. Reineke LH, Wood Flower, U.S. Department of Agriculture, Forest Products Laboratory, U.S. Forest Service Research Note FPL-0113; 1966.
9. Clemons CM, Wood flour. In: Xanthos M (ed) *Functional fillers for plastics*, 2nd ed. Wiley-VCH, Weinheim. 2010;269–290.
10. Karinkanta A, Ämmälä MI, Jouko N, Fine grinding of wood – Overview from wood breakage to applications, *Biomass and Bioenergy*. 2018;113:31-44.
11. Hogan US, Akpan GA, Essien OA, Wood flour moulding technology: Implications for technical education in Nigeria. *African Research Review*. 2011;5(2):233-242.
12. Dongmei Y, Chuanshan Z, Chaojun W, Daiqi W. Wood powder used in paper

- making to improve bulkiness. *Advanced Materials Research*. 2015;550-553:3352-3355.
13. Lee JY, Kim CH, Seo DJ, Lim GB, Kim SY, Park JH, Kim EH. Fundamental study on developing wood powder as an additive of paperboard, *TAPPI Journal*. 2013;13(11): 17-21.
 14. Dölle K, Zier S, Application of Cellulosic-Based Wood Additives for Recycled Paper Applications – A Pilot Paper Machine Study, TAPPI, PaperCon, Indianapolis Conference Center; 2019, Indianapolis, IN, USA.
 15. Sung JY, Kim DS, Lee JY, Seo YB, Im CK, Gwon WO, Kim JD. Application of conifer leave powder to papermaking process as an organic filler. *Journal of Korea TAPPI*. 2013;46(4):62-68.
 16. Park, JH, Lee, JY, Kim, CH, Kim EH, Effects of Lignocellulosic Bulk agents Made from Agricultural Byproducts on Physical Properties and Drying energy Consumption of Duplex Board, *BioResources*. 2015;10(4):7889-7897.
 17. TAPPI T 205 sp-12. Forming handsheets for physical tests of pulp.
 18. TAPPI T 211 om-02. Ash in wood, pulp, paper and paperboard: combustion at 525°C.
 19. TAPPI T220 sp10. Physical testing of pulp handsheets.
 20. TAPPI T227 om-09. Freeness of pulp (Canadian standard method).
 21. TAPPI T 402 sp-13. Standard conditioning and testing atmospheres for paper, board, pulp handsheets.
 22. TAPPI T 403 om-02, "Bursting Strength of Paper".
 23. TAPPI T404 cm-92. Tensile breaking strength and elongation of paper and paperboard.
 24. TAPPI T 410 om-08. Grammage of Paper and Paperboard (Weight per unit area).
 25. TAPPI T 411 om-10. Thickness (caliper) of paper, paperboard and combined board.
 26. TAPPI T412 om-06. Moisture in pulp, paper and paperboard.
 27. TAPPI T494 om-06. Tensile properties of paper and paperboard.
 28. TAPPI T 538 om-08. Roughness of paper and paperboard (Sheffield method).
 29. Rettenmaiern Söhne. Datasheet Natural woodmeal.
 30. Blechschmidt J, Altpapier Regularien-Erfassung-Aufbereitung-Maschinen und Anlagen- Umweltschutz, Fachbuchverlag Leipzig; 2011.
 31. ISO 16065-2:2007, Pulps-Determination of fibre length by automated optical analyses - Part2: Unpolarized light method.

© 2020 Dölle and Zier; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

*The peer review history for this paper can be accessed here:
<http://www.sdiarticle4.com/review-history/53847>*