***Original Research Article***

# Spruce Wood Flour for Paper Applications – A Handsheet Study

## ABSTRACT

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It should contain aims, study design, place and duration of study, methodology, results and conclusion.

This study shows that spruce wood flour can be an alternative cellulosic-based wood additive for papermaking. This study used unbleached wood flour with a particle distribution between 200 µm to 500 µm and bleached and unbleached wood flour with particle size distribution between 70 µm to 150 µm.

Wood flour was added at levels of 2%, 4%, 6%, 8% and 15% based on oven dry fiber content for the first part of the study. For the second part of the study, starch at a level of 0.25%, 0.50%, 0.75%, 1.00%, 1.25%, and 1.50% based on OD fiber content is added to the suspension. The basis weight of the handsheet manufactured was 75 g/m².

Bulk increased from 2.20 cm³/g to a maximum of 2.80 cm³/g for 15% wood flour addition. Maximum tensile index achieved was 24.75 Nm/g based on a base sheet value of 20.05 Nm/g. Addition of starch has a positive influence on the tensile index, with a maximum value of 41.41 Nm/g at 1% addition. Brightness value of the manufactured handsheets decreased gradually for the unbleached wood flour. Bleached wood flour showed a 1%-point increase above the base sheet brightness of 88.51%.

Addition of starch increased the brightness value from 88.51% of the base sheet by up to 4.5%. An opacity increase was achieved for all wood flour additions with the highest opacity value of 95.68% at an addition of 15% wood flour. Addition of starch can decrease the opacity value of up 1.5% points.

Addition of wood flour resulted in a decrease in smoothness by increasing the airflow from the base sheet value of 2564 ml/min by 385 ml/min. at 8% wood flour addition. Adding a line pressure of 1.673 kN/m to simulate calendering resulted in an improved smoothness by reducing the airflow of up to 447 ml/min.

Addition of starch showed an overall increase of smoothness by reducing the airflow number by up to 600 ml/min for sheets with and without line pressure.

*Keywords: Wood flour, additive, papermaking, handsheets, paper properties*

## 1. INTRODUCTION

Paper today is produced from renewable hardwood and softwood materials. Recycling of paper products has improved the environmental footprint of the paper industry in the past decades [1]. Despite this, the paper industry is increasing their efforts in making paper more sustainable, biodegradable and eco-efficient. However, ever rising production cost for paper and board products and their application demand new solution of utilizing raw materials for the production process. 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 [2].

One of these renewable materials that can be added to the papermaking process as additive is Wood Flour (WF). WF is known since the early 1900s [3]. The first WF patent was issued for the production process of phonographic records and other articles. The US. Patent No.1,406.938 was granted to John Cunningham, a resident in Glens Falls in New York State on Feb. 14, 1922 [4]. According to Reineke (1966) [5], WF are wood particles manufactured by grinding selected wood residues. WF can be produced by various grinding and sieving processes of sawdust to sizes between 20µm to 500µm with a size ratio of 1:1 [6]. Karinkanta et al. describes that the manufacturing process today can consist of a thermal, chemical and enzymatic pretreatment before wet milling, dry milling and sieving techniques are applied [7]. Commercial applications for WF today are mainly in the area of Wood Plastic Composites (WPC) and moulding technology applications for articles such as furniture parts, dishes and toys (Hogan et al. 2011) [8].
Recently WF with a size of 200 µm o 450 µm has been investigated in a handsheet laboratory study by Dongmei et al. [9]. He showed that bulk can be improved, and mechanical pulp be replaced. Lee et al. [10] showed that wood powder added to duplex board increase bulk of the produced board paper. Sung et al. [11] showed that powder produced from conifer leaves can be an alternative organic filler source to wood flour in paperboard applications.
Park et al. [12] investigated flour from wood and ground agricultural byproducts for a paperboard application, showing that bulk and drying can be improved, but paper strength is decreasing. However, WF has not been the focus in recent investigations as an alternative cellulosic-based wood additive for papermaking. This handsheet study compares three commercial varieties of spruce WF at an addition of 2%, 4%, 6%, 8% and 15% to a 75 g/m² paper product.

## 2. MATERIAL AND METHODS

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

### 2.1 TAPPI Methods

Pulp refining was done according to T 200 sp-06 “Laboratory beating of pulp (Valley beater method) [13], Handsheets for physical testing were prepared in accordance with T 205 sp-06, “Forming handsheets for physical tests of pulp” [14], Physical testing of handsheets was performed in accordance to T 220 sp-06, “Physical testing of pulp handsheets” [15], the freeness of pulp was measured as Canadian Standard Freeness (CSF) according to T 227 om-09 “Freeness of pulp (Canadian standard method)” [16]. “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” [17]. Tensile strength was measured in accordance with T404 cm-92, “Tensile breaking strength and elongation of paper and paperboard” [18]. Basis weight was measured with T 410 om-08. “Grammage of Paper and Paperboard (weight per unit area)” [19]. The paper thickness was measured by T 411 om-10 “Thickness (caliper) of paper, paperboard, and combined board” [20]. Moisture content of pulp was determined by T412 om-06 “Moisture in pulp, paper and paperboard” [21]. Opacity of paper handsheets was performed according to T 425 om-06, “Opacity of paper (15/d geometry, illuminant A/2°, 89% reflectance backing and paper backing) [22]. Brightness of pulp was measured according to T 452 om-08, “Brightness of pulp, paper and paperboard (directional reflectance at 457 nm)” [23]. Tensile strength was performed following T494 om-06, “Tensile properties of paper and paperboard (using constant rate of elongation apparatus)” [24]. Smoothness/Roughness of the manufactured handsheets was tested according to T 538 om-08, "Roughness of paper and paperboard (Sheffield Method)" [25].

## 2.1 Materials

For this study 75 g/m²handsheets are produced from 80% Elemental Corine Free (ECF) Eucalyptus bleached Kraft pulp, and 20% Northern Bleached Softwood Kraft (NBSK) pulp. Prior to handsheet forming the pulp is refined to a Canadian Standard Freeness (CSF) level of 360 ml following T 200 sp-06 method [16]. WF was added based on Oven Dry (OD) fiber content prior to handsheet forming following T 220 sp-06 method [18]. Spruce WF was obtained from J. Rettenmaier & Söhne, Rosenberg, Germany. WF1 and WF2 were unbleached with a particle size distribution of 200µm to 500µm and 70µm to 150µm respectively. WF3 was bleached with a particle size distribution of 70 µm to 150 µm.
Starch used in this study was cationic starch cooked at a 3% solution at 90°C for 20 minutes prior to handsheet making, cooled down to 30°C and added to the pulp WF suspension prior to handsheet forming.

## 3. RESULTS AND DISCUSSION

All handsheets were made and tested according to TAPPI standards. In the first part of the study WF1, WF2, and WF3 was added at levels of 2%, 4%, 6%, 8% and 15% based on OD pulp. In the second part, handsheets were prepared with the addition of starch at a level of 0.25%, 0.50%, 0.75%, 1.00%, 1.25%, and 1.50% based on OD fiber content. Handsheets with and without starch for the smoothness measurement were exposed to a line pressure of 1.673 kN/m to simulate calendering.
Fig.1 shows that the basis weight of the base sheet was 64.5 g/m². Manufactured handsheets with WF1 had a basis weight range of 72.20 g/m² to 76.50 g/m², WF2 resulted in a basis weight range of 72.40 g/m² to 80.30g/m², and WF3 in a basis weight range of 71.70 g/m² to 76.90 g/m². The basis weight increase for all WF follows the same pattern except for WF1 at a dosage of 4%, 8%, and 10% were a 3.6 g/m², 2.1 g/m², 3.5 g/m² lower basis weight was achieved respectively compared to WF 2 which had the highest basis weight at all WF dosage levels. WF3 basis weight levels are very comparable to WF 2 except for the 15% dosage were a 1.7 g/m² lower basis weight was the result for WF 1 and 4.1 g/m² for WF3.

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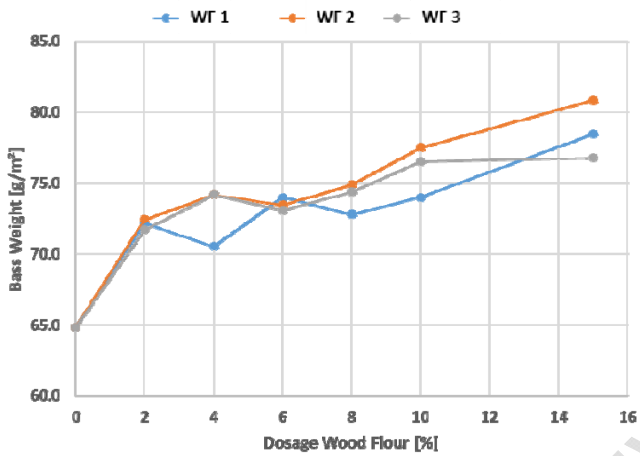


**Figure 1: Basis weight**

The graph in Fig.2 shows the basis weight achieved for WF1 to WF3 with the addition of starch at 0.25%, 0.50%, 0.75%, 1.00%, 1.25%, and 1.50% based on OD fiber content. The percentage of the WF addition was chosen based on Fig.1. WF1 addition was 2%. The addition of WF2 unbleached and WF3 bleached with the same particle size distribution was 4% and 8% respectively in order to compare unbleached and bleached WF at the same basis weight for the starch addition. Fig. 2 shows, that starch serves as a good retention aid, bonding the fine fibers and WF into the produced handsheet. As a result, the basis weight of the handsheet increases from the base sheet of 65.00 g/m² of about 10.00 g/m² at a starch addition of 0.25%. For a starch addition of 0.50%, 0.75%, 1.00%, 1.25%, and 1.50% the basis weight stays constant at around 75.00 g/m².

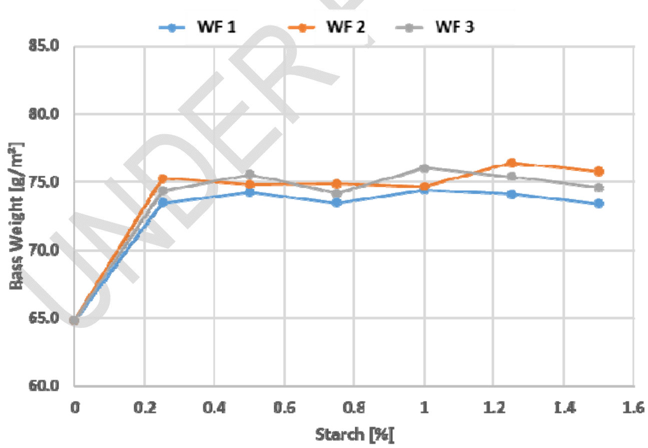


**Figure 2: Basis weight with starch**

Fig. 3 shows that addition of WF increases the bulk from 2.20 cm³/g of the base sheet to a maximum of 2.43 cm³/g, 2.80 cm³/g, and 2.61 cm³/g for the 15% WF addition of the manufactured handsheets for WF1, WF 2, and WF3 respectively. For WF1 and WF2 a bulk reduction resulted for the 2% addition to 2.10 cm³/g and 2.06 cm³/g respectively. WF2 showed in addition lower bulk value for the 4% and 8% addition at 2.09 cm³/g and 2.17 cm³/g respectively.

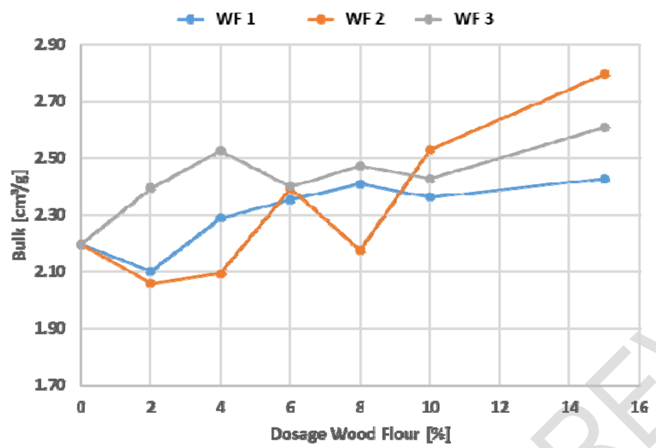


**Figure 3: Bulk without starch**

Addition of starch reduces the bulk, as shown in Fig.4 from 2.20 cm³/g of the base sheet to a minimum of 1.61 cm³/g, 1.67 cm³/g, and 1.58 cm³/g for the 1.5% starch addition of the manufactured handsheets for WF1, WF 2, and WF3 respectively. Bulk reduction for WF3 was identical for all starch additions. WF1 and WF2 had the lowest reduction at 0.25% starch addition with 2.06 cm³/g and 1.91 cm³/g respectively.

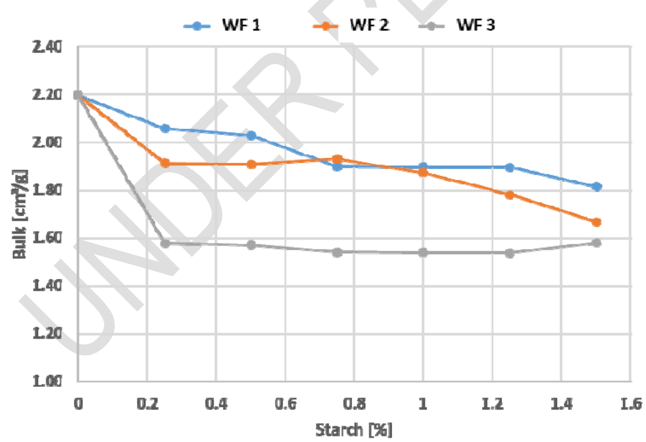


**Figure 4: Bulk with starch**

Fig. 5 shows that WF3 has an increase in tensile index only for an addition of 2% from the base value of 20.05 Nm/g to a value of 23.67 Nm/g. WF2 had its maximum tensile index at an addition of 4% with a value of 23.13 Nm/g. At an addition of 8%, 10%, and 15% the tensile index was lower at 19.17 Nm/g, 20.60 Nm/g, and 17.20 Nm/g respectively. WF1 had its maximum tensile index at an addition of 8% with a value of 24.75 Nm/g. At an addition of 15% the tensile index was lower at 18.50 Nm/g.

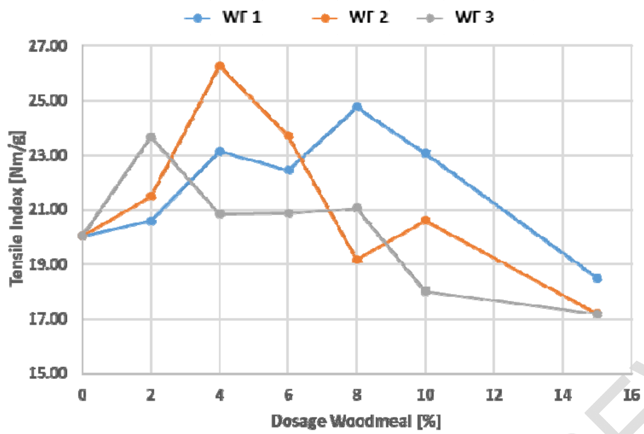


**Figure 5: Tensile index without starch**

Addition of starch and WF increases the tensile index for all WF1 to WF3 as shown in Fig. 6. Above the base sheet value of 20.05 Nm/g. For WF1 has its peak at a starch addition of 1% with a tensile index value of 30.70 Nm/g. WF2 and WF3 have their maximum tensile index at 1% with 41.41 Nm/g and 0.75% with a value of 36.26 Nm/g respectively.

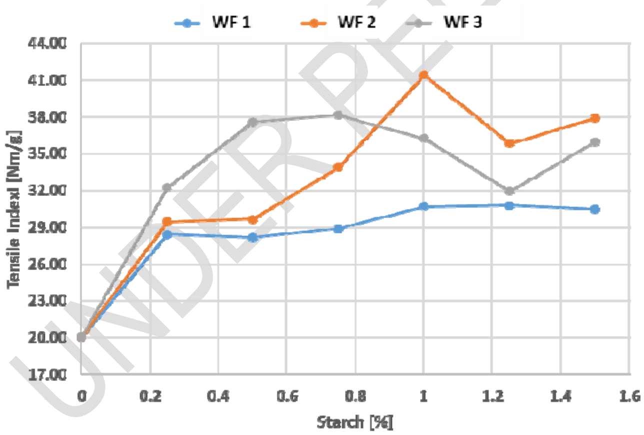


**Figure 6: Tensile index with starch**

Fig. 7 and Fig. 8 show the brightness value of the manufactured handsheets for different additions of WF1, WF2, and WF3. A gradually decreasing brightness value with increasing WF content can be observed for WF1 and WF2, with the lowest brightness of 83.27% and 85.92% respectively, based on the base sheet brightness of 88.51%. WF3 showed a up to1% point brightness gain compared to the base sheet brightness of 88.51.

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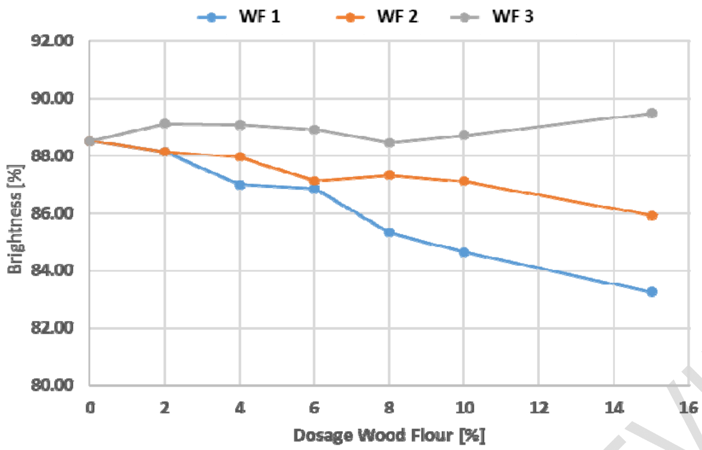


**Figure 7: Brightness**

Addition of starch increased the brightness value from 88.51% of the base sheet by up to 4.5% for the bleached WF3 and up to 4% for WF2. WF1 resulted in a up to 2.5- points brightness increase. For all WF, a starch addition of 0.25% resulted in the highest brightness increase. For starch additions of 0.55, 0.75%, 1.00%, 1.25%, and 1.50%, except for WF1 and WF2 which had a brightness increase of 3.5%-points at a starch addition of 1.5%.

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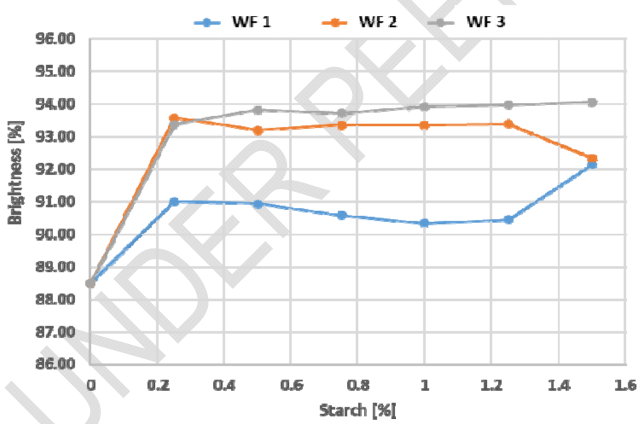


**Figure 8: Brightness with starch**

Fig. 9 and Fig. 10 show the opacity value of the manufactured handsheets for different additions of WF1, WF2, and WF3. The opacity value of the base handsheet was 85.64%. A gradually increasing opacity value with increasing WF content can be observed for WF1, WF2, and WF3, with the highest opacity of 95.68% and 92.14% for WF1 and WF3 respectively at the addition of 15%. WF 2 had its highest opacity value at an addition of 10% with an opacity value of 91.13%.

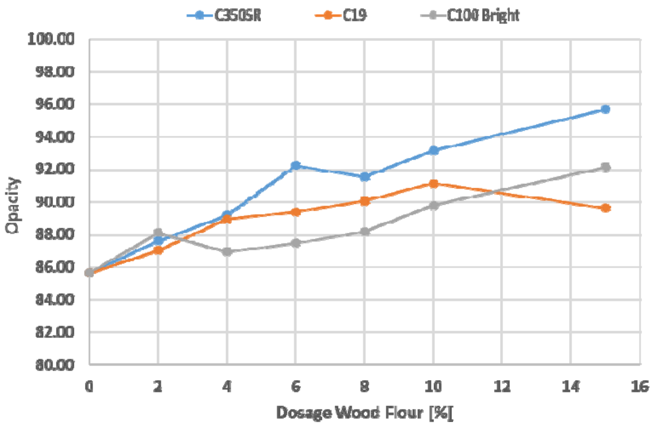


**Figure 9: Opacity**

Addition of starch decreased the opacity value from 85.64% of the base sheet by up to 0.9% points for WF1, up to 1.5% points for WF2, and up to 3.2% points for WF3. At a starch addition of 1% WF1 showed a 0.3%-point opacity increase based on the base value of 85.64%.

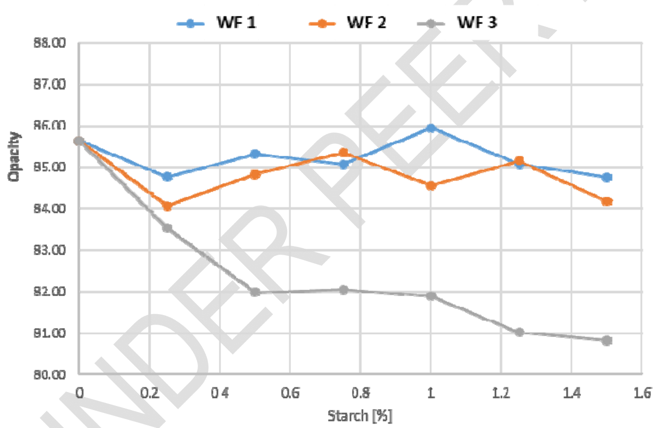


**Figure 10: Opacity with starch**

Fig. 11 shows the smoothness of handsheets for WF1, WF2, and WF3. The initial value for smoothness was 2564 ml/min. for the base sheet. Addition of WF1, WF2, and WF3 decrease the smoothness of the paper due to the higher airflow value. WF1 increase up to 385 ml/min. at 8% WF addition, WF2 and WF3 showed an increase of 314 ml/min. and 301ml/min. at 15% WF addition respectively.

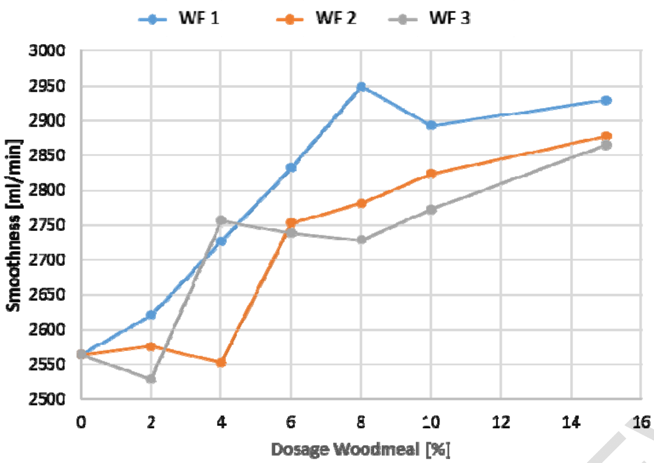


**Figure 11: Smoothness without line pressure**

Fig. 12 shows smoothness values with a line pressure of 1.673 kN/m applied to simulate calendaring. The line pressure reduces the airflow and improves smoothness of the manufactured handsheets containing WF. Applying the line pressure reduces airflow by 362 ml/min. to 2202 ml/min. for the base sheet, WF1 had a reduction of 31 ml/min. to 118 ml/min., WF2 a reduction between 77 ml/min. to 447 ml/min, WF3 a reduction of 104 ml/min. to 335 ml/min.

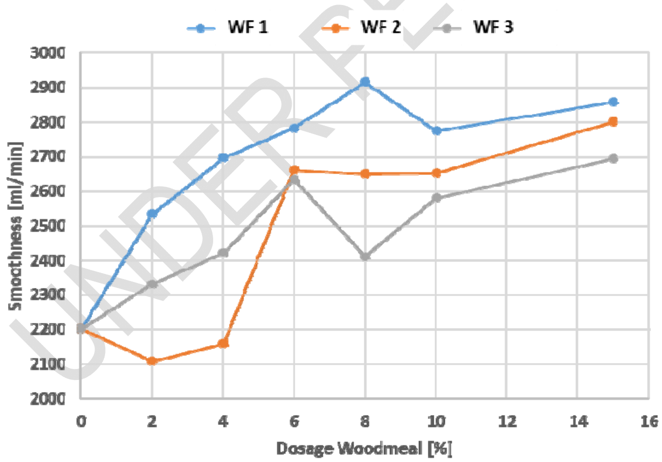


**Figure 12: Smoothness with 1.673 kN/m line pressure**

Graphs of Fig. 13 and Fig. 14 show the smoothness value if starch is applied for handsheets containing WF1, WF2, and WF3. The initial value for smoothness was 2564 ml/min. for the base sheet. Addition of starch showed an overall increase of smoothness by reducing the airflow number. WF1 had a maximum decrease below the air flow number of the base sheet of 298 ml/min., WF2 showed a decrease of 600 ml/min., and WF3 showed a 484 ml/min. air flow decrease.

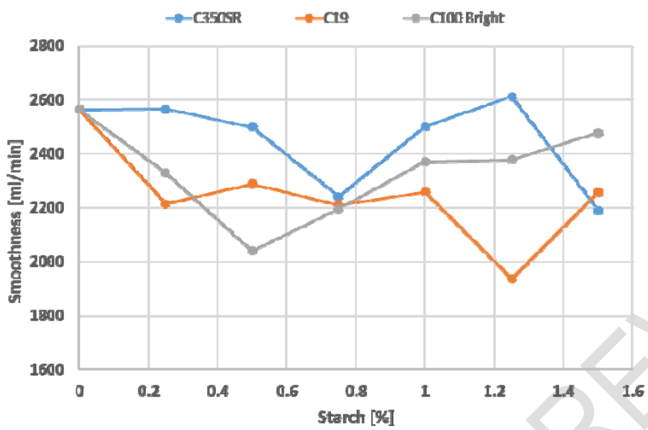


**Figure 13: Smoothness with starch and without line pressure**

Fig. 14 shows smoothness values with a line pressure of 1.673 kN/m to the starch containing handsheets to simulate calendaring. The line pressure reduces the airflow and improves smoothness of the manufactured handsheets containing WF. Applying the line pressure reduces airflow by 362 ml/min. to 2202 ml/min. for the base sheet. WF1 had a reduction of up to 298 ml/min., WF2 a reduction of up to 600 ml/min., and WF3 a reduction of up to 484 ml/min. of air flow.

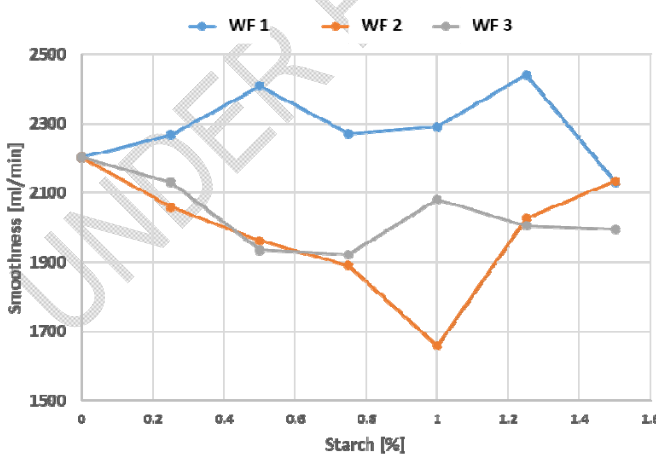


**Figure 14: Smoothness with starch and line pressure of 1.673 kN/m**

## 4. CONCLUSION

This study shows that WF can be considered an alternative cellulosic-based wood additive for papermaking. This handsheet study showed that spruce WF with a particle distribution between 200 µm to 500 µm and bleached and unbleached WF with a particle distribution of 70 µm to 150 µm respectively could have benefits for paper production. WF added at levels of 2%, 4%, 6%, 8% and 15% to a 75 g/m² handsheet increases bulk from 2.20 cm³/g of the base sheet to a maximum of 2.80 cm³/g for the 15% WF addition. Increase of tensile index can be achieved at up to 8% WF addition but is dependent on the WF type used. Maximum tensile index achieved was 24.75 Nm/g based on a base sheet value of 20.05 Nm/g.
Addition of starch has a positive influence on the tensile index, with a maximum value of 41.41 Nm/g at 1% addition. Bulk values decreased by the addition of starch at all levels.
Brightness value of the manufactured handsheets decreased gradually for the unbleached WF. Bleached WF showed a 1%-point increase above the base sheet brightness of 88.51%.
Addition of starch increased the brightness value from 88.51% of the base sheet by up to 4.5%. An opacity increase was achieved for all WF addition with the highest opacity value of 95.68% at an addition of 15% WF. Addition of starch can decrease the opacity value of up 1.5% points.
Addition of WF resulted in a decrease in smoothness by increasing the airflow from the base sheet value of 2564 ml/min by 385 ml/min. at 8% WF addition. Adding a line pressure of 1.673 kN/m to simulate calendering resulted in an improved smoothness by reducing the airflow of up to 447 ml/min. by WF addition.
Addition of starch showed an overall increase of smoothness by reducing the airflow by up to 600 ml/min. based on the WF used. By applying a line pressure of 1.673 kN/m to the starch, containing handsheets smoothness can be improved by an additional 600 ml/min. in airflow reduction.

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**Comment [HSMD5]:** the conclusion can be short.

**Comment [HSMD6]:** Wrong format.

**Reference to a journal**:
*For Published paper:*

1. Hilly M, Adams ML, Nelson SC. A study of digit fusion in the mouse embryo. Clin Exp Allergy. 2002;32(4):489-98.

**Comment [HSMD7]:** Journal name should be written either in full name or abbreviated name, but not a mixture of both.

**Comment [HSMD8]:** Journal name should be written either in full name or abbreviated name, but not a mixture of both.

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19. TAPPI T404 cm-92 Tensile breaking strength and elongation of paper and paperboard
20. TAPPI T 410 om-08. Grammage of Paper and Paperboard (weight per unit area).
21. TAPPI T 411 om-10. Thickness (caliper) of paper, paperboard, and combined board.
22. TAPPI T412 om-06. Moisture in pulp, paper and paperboard.
23. TAPPI T414 om-12. Internal tearing resistance of paper (Elmendorf-type method).
24. TAPPI T425 om-06. Opacity of paper (15/d geometry, illuminant A/2°, 89% reflectance backing and paper backing).
25. TAPPI T 452 om-08. Brightness of pulp, paper and paperboard (directional reflectance at 457 nm).
26. TAPPI T494 om-06. Tensile properties of paper and paperboard.
27. TAPPI T 538 om-08. Roughness of Paper and Paperboard (Sheffield method)