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# Improved Breaking Length Development of Unbleached Softwood Kraft Pulp in PFI Refining by Addition of Primary Fines

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## Abstract

Nowadays the so called fines fraction is experiencing increasing interest for the papermaking society, as an essential component of any papermaking pulp. It shows distinctive properties affecting both production process and product properties to a large extent. Several research groups have experimented with either primary and/or secondary fines to assess their corresponding properties in the recent years. When it comes to the influence of primary fines on paper and process, these studies do not always show consistent results, attributed to different raw materials considered, to retention issues during sheet forming or maybe to formation issues arising at higher dosages.

This work focuses on the clarification, how primary fines of unbleached softwood kraft pulp (Kappa number ~27) influence the product and process parameters, especially if the total fines amount is risen compared to the original stock. Primary fines are separated from the pulp using a laboratory pressure screen to be added again in controlled amounts afterwards. Thereby three pulp blends, showing a primary fines content of around 5%, 9% and 12% where prepared. These pulp blends were refined in a PFI mill at 1000, 4500 and 6000 revolutions and compared with the unbeaten reference. The refining treatment mainly resulted in fiber flexibilisation and internal fibrillation while barely any secondary fines were produced.

Because retention of the fines material might be an issue, a Rapid-Köthen sheet former with white water recirculation was used. The results of paper testing show that the tensile index develops at lower specific refining energy when adding primary fines prior to refining due to increased densification of the sheets. The results also show increased dewatering resistance (Schopper-Riegler) at a given tensile index, while densification and air permeability (Gurley) are comparable. Considering the linear relationship between tensile index and sheet density – independent of the fines content – it can be concluded that fibre flexibilisation and primary fines both enhance fibre-fibre bonding and that both strategies result in the same increase in mechanical strength with the downside of slightly reduced dewatering in case of the introduction of primary fines.

## Introduction

When talking about pulp, it is necessary to differentiate between the coarse fiber material and the fines material. Fines again can be separated in primary fines, which are created during the pulping process, and secondary fines which are a product of refining and mechanical stresses in stock preparation. The morphological character of the produced fines is different depending on their origin. Primary fines mainly consists of flake like fines, which are mostly ray cells and fragmental parts from middle lamella and primary fiber wall. Secondary fines are mainly fibrillar fines torn out from the secondary wall. [1][2]

Several studies have been done by different groups focusing on the technological properties of these fines and the effects of their removal or addition. Because of the diversity of experimental designs, these studies did not always show consistent results. Chauhan et.al. for example show that the addition of primary fines, separated from bleached hardwood pulp by means of a Bauer McNett classifier, up to 10 and 20% total fines content prior to refining, leads to a reduced strength potential after PFI refining compared to the reference without additional primary fines [3]. Feirreira et.al. on the other hand show that removal of primary fines from unbleached hardwood kraft pulp, leads to a decrease in tensile and burst index, but an increase in tear index [4]. Similar results are presented by Bäckström et al. in an experimental design where fines were added instead of removed. It is shown that the addition of either primary or secondary fines to refined fibers allows an improvement of tensile index, burst index and TEA [2].

This work focuses on the primary fines of a softwood kraft pulp and the effect of different primary fines ratios in the pulp to shed more light on their role when it comes to pulp properties in the unrefined state and especially the development of said properties during refining and the accompanied energy saving for beating.

## Materials and Methods

### *Material*

An industrial never-dried unbleached softwood kraft pulp with a kappa-number of around 27 was used in all trials. The primary fines content of the pulp was 5%. A fraction of these primary fines was separated from the stock using a lab scale pressure screen implemented at the Institute of Paper, Pulp and Fiber Technology at Graz University of Technology. The aggregate was equipped with a 100µm hole screen. The accept passing the screen with a dry matter of approximately 0,01%, was collected in vessels for sedimentation. The supernatant was decanted after adequate time for sedimentation – to ensure no further fractionation – to reach a dry content of nearly 0,5% for subsequent application during sheet forming. The coarse fraction was discarded. The primary fines were added to the reference pulp (fines content 5%) to reach a total fines content of 9 and 12%.

### *Methods*

Each mixture was disintegrated in the lab disintegrator according to ISO 5263-1. Afterwards the samples were refined in the PFI-mill for 1000, 4500 and 6000 revolutions (rev) (ISO 5264-2). Each blend and corresponding refining intensity was prepared twice, to have enough material for all measurements and investigations.

Hand sheets of 80g/m² were prepared according to ISO 5269-3 on a Rapid-Köthen handsheet former using white water recirculation. Due to the special focus on the primary fines and their technological impact, it was necessary to make sure that no fines are lost because of retention issues. To avoid this matter the first four handsheets were discarded, to reach an equilibrium of fines in the recirculated white water [5] and thereby 100% retention.

All hereafter described analytical methods were applied on all blends as well as on the reference pulp. Fibre morphology was determined using a L&W Fiber Tester+. This optical flow microscopy analyzer has an optical resolution of 3.3µm/pixel [6]. Samples are prepared at approximately 0.1g dry matter and measurements were repeated three times. For each repetition a minimum of 100000 particles was detected. Results are discussed based on the length-weighted fiber length distributions according to ISO 16065-1. The total fines content was determined using the Britt Dynamic Drainage Jar (BDDJ) according to SCAN-CM 66:05 using a 200mesh screen. Additionally the drainability of the samples was determined according to ISO 5267-1 (Schopper Riegler method).

Handsheet testing was done after 24 hours in the climate room at 23°C and 50% relative humidity. We determined apparent sheet density according to ISO 534, breaking length according to ISO 1924-2 and Gurley air permeability according to TAPPI 460 om-16.

## Results

The fibre morphology of the pulp is of high importance when it comes to its technological properties. Among the several properties provided by commercial flow cells the fiber length distribution can be considered as the key factor of morphology and it will definitely be affected substantially due to the addition of fines. This is addressed in Fig. 1. based on a cummulative length weighted $Q_1$ depiction. In contrast to the obvious increase in fines content due to the addition of primary fines, no relevant changes in fines content nor in the fibre length distribution overall is noticable due to refining. This shows that secondary fines were barely generated and hardly any shortening of long fibers occurred during refining, indicating that the PFI-mill treatment leads mainly to fibre flexibilisation due to internal fibrillation which has also been reported elsewhere [7][8][9]. Therefore the technological changes due to the PFI-treatment has to be attributed mainly to fibre flexibilisation and higher conformability of the fibres.

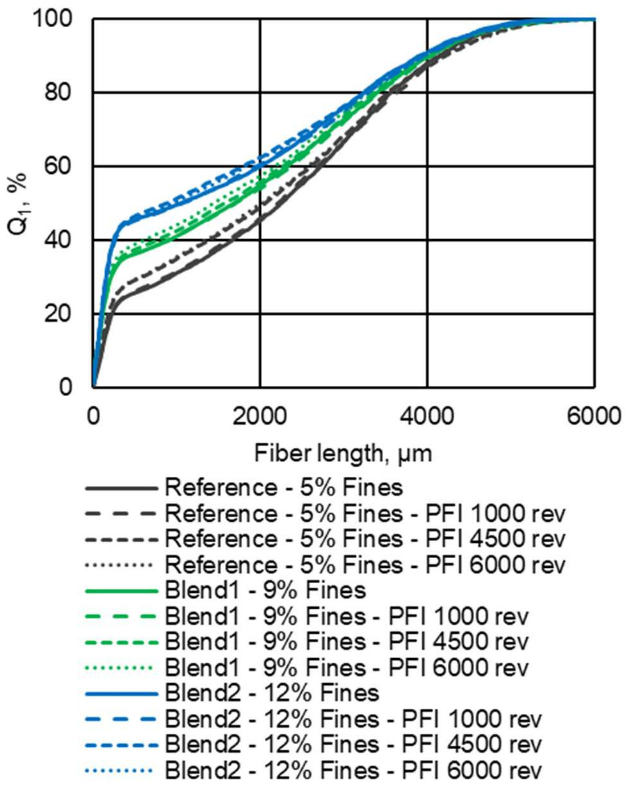


Fig. 1. Cumulative length weighted fiber length distribution $Q_1$ of blends after beating in comparison with the unbeaten references

Dewatering ist the main paramater we expect to be affected due to fines addition. Still, in the unrefined state the effect on dewatering (based on °SR) is barely noticeable (Fig. 2a). For low refining intensity at 1000rev a slight increase in dewatering resistance is noticeable due to the added amount of primary fines. This behavior becomes substantial for the higher refining intensities, as for 4500 and 6000rev in the PFI mill. At the upper end of our investigation the increase in °SR at 12% primary fines content is more than double that of the reference at 5% primary fines content.

A similar behavior compared to dewatering is evident for air permeability (Fig. 2b). While there is only a minor effect for lower refining intensity, the Gurley seconds are increased substantially for higher intensities.

It seems, that the additional fines present in the pulp tend to affect air permeability and dewatering especially in already denser networks formed of more flexible fibers where they are capable of blocking the remaining pores.

When it comes to mechanical properties there is a clearly positive effect on breaking length (Fig. 2c) due to the addition of primary fines. This effect is reduced for higher refining intensities and therefore already densified sheets up to the point where no significant difference in breaking length is observable anymore after 6000rev, in the PFI mill.

Summing up there is clearly a strong effect of the dosed primary fines on dewatering and air permeability especially at higher refining intensities where the added fines seem to have a tendency to block the already fine pores of the densified sheet. Breaking length is mainly improved in the unrefined state and at a low refining intensity whilst being virtually unaffected for the highest refining intensity (6000 Rev. PFI).

a)
b)
c)

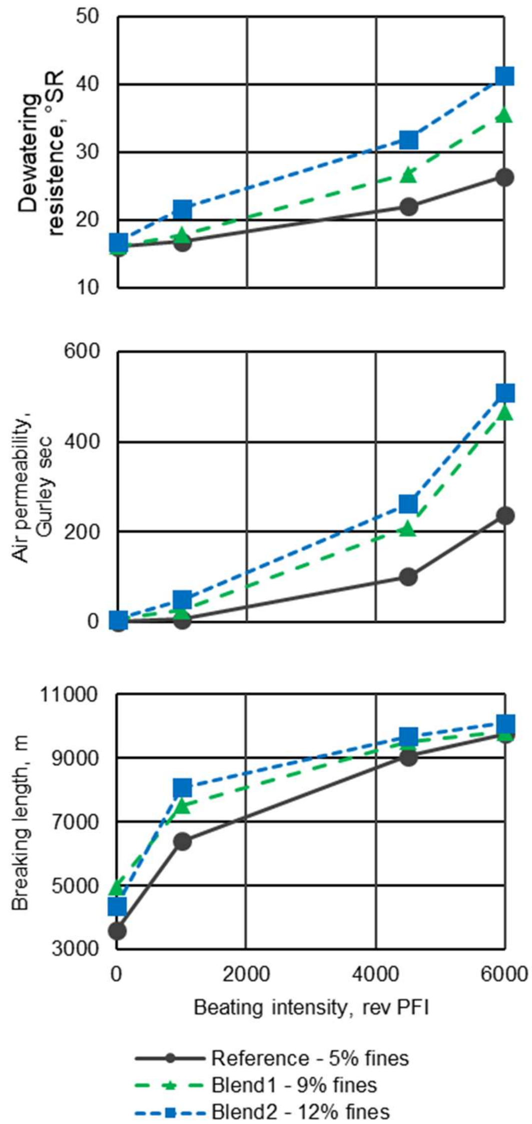


Fig. 2. a) Development of dewatering (Schopper-Riegler), b) Gurley air permeability and c) breaking length due to beating

However, when it comes to an application of such a softwood bleached kraft pulp in paper production it is mainly the properties at a certain breaking length that are of interest as the pulp is refined to reach a certain strength level with the corresponding dewatering properties being merely a side effect. Looking at the direct relationship between air permeability and tensile strength (Fig. 3) or dewatering and tensile strength (Fig. 4) it is evident that there is not much difference visible in this relationship whether primary fines are added or not. The development of tensile strength (breaking length) levels out after a certain refining intensity whilst dewatering resistance and gas-barrier properties are increasing further. In case of dewatering, the blend with 12% primary fines seems to show a slightly higher °SR-value for a given breaking length indicating higher dewatering resistance even in the region of lower refining intensities, for 9% such a trend cannot be observed. In case of air permeability no significant difference is evident. Above of that it is evident in these diagrams (Fig. 3+Fig. 4) that it is not possible to produce higher mechanical strength by the addition of primary fines. The maximum tensile strength is determined by the pulp itself and is a kind of intrinsic pulp property. Several publications are demonstrating this behavior for mechanically modified pulps due to refining and also in consequence of fines addition [1][8][10][11].

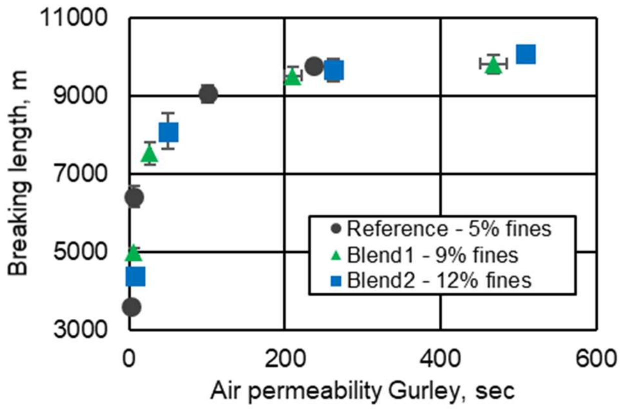


Fig. 3. Air permeability (Gurley) compared with breaking length

Both air permeability and dewatering resistance are affected because of a certain densification of the sheet/the filter mat due to flexibilisation of the fibres on the one hand and blocking of the pores by the present fines on the other. If we look at sheet density directly – keeping in mind that the determination of sheet density is also always strongly affected by formation and roughness of the sheets – we can again directly relate sheet density to breaking length as it is shown in Fig. 5. There is clearly a linear relationship between sheet density and tensile strength which is to be expected as higher density automatically increases the relative bonded area and thereby tensile properties. How this densification is achieved does not seem to affect this relationship too much. It can be achieved by fibre flexibilisation, fiber shortening and/or production of fiber fines. The strong effect of fines when it comes to increased sheet densification and its consequence for mechanical properties was already shown in the past.[12]

Still, in our case there seems to be a slightly stronger increase in breaking length than in sheet density due to the addition of primary fines in the region between densities of 550 up to 675kg/m³. An explanation for this phenomenon could be that the increased amount of primary fines in case of less flexible pulp fibers generates additional bonded area due to an aggregation of the fines in the interstices between two crossing fibers during dewatering. The improvement for fiber-fiber bonding due to fines acting as a kind of bridging material, was already described [2]. For a higher degree of flexibilization, this effect is less pronounced and no significant difference between the reference and the two blends is evident for the denser sheets above 700kg/m³. Still, the fine material is closing the voids more and more whilst no longer affecting the apparent density. This leads to the above mentioned lower air permeability and reduced dewatering at comparable strength properties.

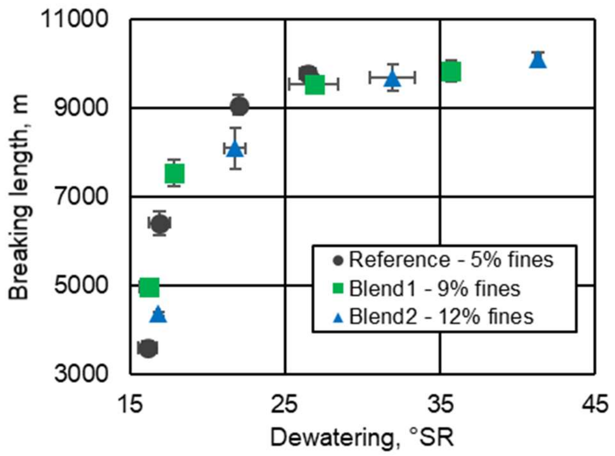


Fig. 4. Dewatering (Schopper-Riegler) compared with breaking length

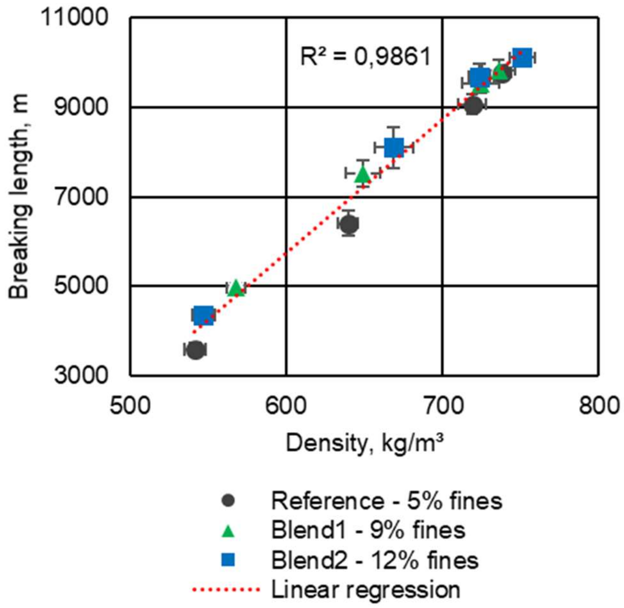


Fig. 5. Relation between density and mechanical strength

However, an increased amount of primary fines does allow to reach a certain strength level with reduced refining efforts and at maybe lower apparent density but with probably slightly reduced dewatering ability.

**Conclusion**

The increase of primary fines in unbleached softwood kraft pulp of the same origin enhances breaking length in the unrefined state as well as at low refining intensities. The maximum tensile strength on the other hand is not increased, but stays at the level of the reference. However, in terms of refining energy the introduction of primary fines would allow to reach a certain strength level at lower energy consumption with the drawback of slightly reduced drainability. The apparent density on the other hand seems to be slightly lower for a given tensile strength in the unrefined state as well as at low refining intensities. At higher refining intensities the increased amount of fines in the – due to fibre flexibilisation in PFI refining – already densified network no longer promotes tensile properties but mainly tends to block pores and thereby increases dewatering resistance and reduces air permeability.

In this study the primary fines do prove to show good bonding ability. A comparison to secondary fines in this respect is not possible based on this study because hardly any secondary fines are produced during the PFI-treatment. This is also an issue when it comes to the applicability of said results under industrial conditions as an industrial refiner will always produce a certain amount of additional secondary fines and will also show some fiber shortening during treatment. The corresponding results in an industrial setup may therefore differ from our laboratory study.

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