The Effect of Fines on Dewatering, Wet and Dry Web Properties

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ABSTRACT

Speed of paper machines is often limited by the drainage rate of the furnish and the mechanical properties of the wet web, i.e. the tension and relaxation properties. In this study, the effects of the fibre properties and fines content on dewatering, dry and wet web properties were determined. The share of long fibres decreased only slightly when the pulp was refined in the Valley beater. More fibre cutting occurred during refining in the ProLab refiner. Tests showed that refining of pulp from SR20 to SR30 and SR70 using a Valley beater or a ProLab refiner increased the dewatering time. The wet and dry tensile strength as well as the residual tension of the wet web at 2% strain also increased. Removal of fines shortened the dewatering time and decreased the wet and dry tensile strength, and the residual tension compared to pulps containing fines. Addition of fines increased the dewatering time as well as the dry and wet tensile strength. The fibre properties affected the residual tension more than the fines content, while the fines content was more important for the wet tensile strength.

INTRODUCTION

The tension and relaxation properties of the wet web are critical for the runnability of paper machines [1,2]. Poor strength and relaxation of the wet paper cause web breaks and can also impair the quality of the dry paper. Recently it has been indicated that, in addition to dry paper properties, also the wet web properties are affected by the wet-end chemistry [3].

Refining of chemical pulp is employed in order to improve bonding ability of fibres thereby forming a strong and smooth paper sheet [4]. The effects include among others cutting and shortening of fibres, generation of fines as well as internal and external fibrillation [5]. Fines are generally highly swollen particles [6] with a large surface area, and they have a great effect on the wet-end chemistry [7]. They fill the spaces between fibres and slow down dewatering [8]. Fines affect the sheet properties by increasing the density and the bonded area of the sheet, thereby increasing the tensile strength [9]. The secondary fines generated during refining of chemical pulp are usually of fibrillar nature [10], which bring fibres into closer contact and enhance fibre-fibre bonding during drying [11].

The presence of fines usually increases the wet web strength. Earlier studies show that addition of kraft fines to long kraft fibres improved the wet tensile strength while the dry content after wet pressing decreased [12]. Fines also increase the shrinkage forces during drying [8].

In this study, the effects of fines on dry and wet web properties as well as on dewatering were studied. Two types of refiners were used, the Valley beater and the Prolab refiner, in order to produce more fines and to introduce changes in the fibres, e.g. internal fibrillation and fibre cutting. Pulp was refined to different degrees of refining, fines were added to original pulp or removed from refined pulp.

EXPERIMENTAL

Materials

Pulp

ECF-bleached pine pulp was obtained from a Finnish pulp mill. The pulp was refined and dewatered at the mill. The pulp was packed as never-dried into airtight polyethylene bags, and kept at -18°C until used for testing. The Schopper-Riegler value (ISO 5267-1) of the pulp after dewatering and freezing was ~20.

Chemicals

$CaCl_2 \cdot 2\ H_2O$ (p.a. Merck) was used as a 1 M aqueous solution for conductivity adjustments. NaOH, $NaHCO_3$ and HCl were used for pH adjustments. NaN_3 was used as a preservative for storage of fines.

Methods

Refining

The pulp was refined using two different laboratory refiners; a Valley beater and a ProLab refiner. The pulp refined in the Valley beater was first soaked for 2 hours, then disintegrated and refined to desired SR value according to SCAN-C 25:76. The pulp used in the ProLab refiner was soaked at a consistency of about 7.2% for 1 h and then disintegrated in the ProLab refiner for 15 min. Following the disintegration, the pulp was diluted to 50 g/L and the pH was adjusted to 6. The pulp was then refined to desired SR values. The rotational speed was 1500 rpm, the pulp flow rate 100 L/min and the specific edge load (SEL) 3.0 J/m. The refiner was equipped with standard long medium (LM) conical fillings, with a crossing edge length of 52 m/rev. A calibration curve displaying specific refining energy (SRE, kWh/t) vs. °SR was used in order to be able to reach different SR values.

Generation of fines

In order to generate fines to add to the original pulp, the pulp was refined in either the Valley beater or the ProLab refiner. Fines are defined as the particles passing a 100 mesh wire in order to ensure that there was enough small particles. In the case of the Valley beater, the pulp was refined to a SR value of 86. The separation of fines was done with a Dynamic Drainage Jar (DDJ) equipped with a 100 mesh wire. The refined pulp was diluted to 10 g/L consistency and filtered through the DDJ. The filtrate was stored in a refrigerator and the fines were allowed to settle. The sediment was centrifuged and 0.01% NaN_3 was added as a preservative. The dry content of the sediment was 0.44%. When the ProLab refiner was used, the pulp was refined to SR 88. The separation procedure was the same as for the fines generated using the Valley beater. The dry content of the sediment was 0.8%. The sediments were stored in a refrigerator until used.

Removal of fines

Some trial points required removal of fines from the pulp suspension. In the case of pulp refined in the Valley beater, the refined pulp was diluted to 1.0 g/L and filtered through the DDJ equipped with a 100 mesh wire in 0.5 L batches. 0.5 L distilled water was added simultaneously to the DDJ. The suspension was filtered and the pulp residue collected. The dry content of the pulp residue was 8.5-9.4%. The pulp residue was diluted and left to stand over night before sheet making. When the ProLab refiner was used, the refined pulp was diluted to 1.0 g/L and filtered through the DDJ equipped with a 100 mesh wire in 1.0 L batches. 5.0 L distilled water was added to the DDJ. The suspension was filtered and the suspension removed from the DDJ when about 0.5 L remained.

Dewatering tests

Dewatering time and air permeability were determined using a dynamic drainage analyzer (Dynamic Drainage Analyzer of Åbo Akademi, Åbo/Turku, Finland, DDÅA) (Fig. 1). The DDÅA is custom built, and is a combined drainage analyzer and sheet former. The DDÅA is computer controlled and has a high repeatability. The outside pressure was adjusted to 1 bar in the experiments. A grammage of 175 g/m^2 was used.

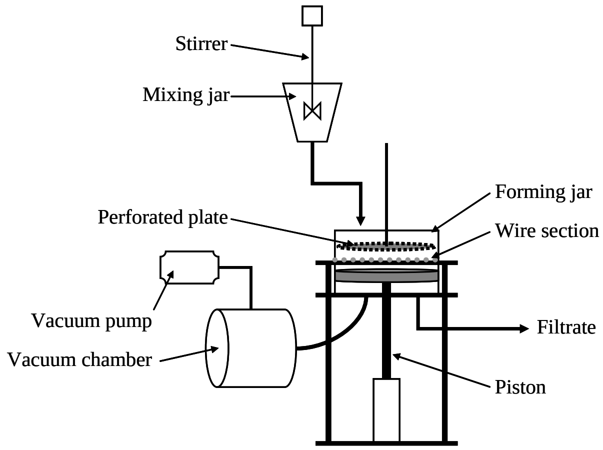


Figure 1. The Dynamic Drainage Analyzer of Åbo Akademi, DDÅA.

Pulp furnishes with a consistency of 5.7 g/L were prepared from refined pulp, refined pulp from which the fines had been removed, original pulp to which fines had been added or from original pulp which had been disintegrated according to ISO 5263 (60°C, 10000 rpm). The conductivity was adjusted to 1.0 mS/cm by addition of $CaCl_2$. The pH was adjusted to 8-8.5 using 1 M NaOH or 1 M HCl. The pulp suspension was stirred for 60 minutes prior to experiments. The pulp suspension was poured into a mixing jar in the DDÅA (Fig. 1). During the first 30 s, the stirrer speed was set to 500 rpm and then the speed was increased to 1000 rpm. After 70 s, a valve was opened and the suspension was sprayed onto the wire. The suspension was mixed with a perforated plate for 30 s before the valve below the wire was opened. The container under the wire had a 0.3 bar vacuum, resulting in removal of water from the suspension and formation of a paper sheet on top of the wire. After the valve under the wire had been opened, the pressure was continuously measured during 60 s. From the obtained graph it was possible to determine the dewatering time (a shift in the slope) and air permeability (the pressure difference between the opening of valve and stabilizing pressure) (Fig. 2). For each test, 1.5 L of pulp suspension was used and 0.5 L of water was poured onto the wire before the pulp suspension was added. The consistency of the pulp suspension on the wire was about 4.3 g/L.

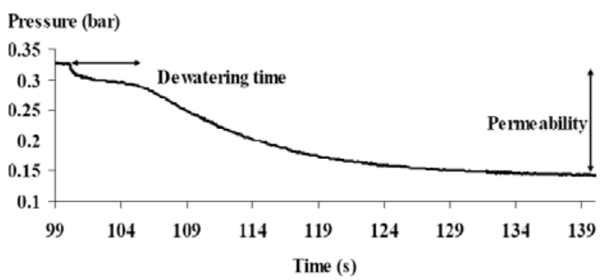


Figure 2. The data from the DDÅA is plotted as the pressure versus the time. From this graph, the dewatering time and air permeability was determined.

Preparation of laboratory handsheets

The conductivity of distilled water was adjusted to 1 mS/cm by addition of $CaCl_2$. The pH was adjusted to pH 8-8.5 using 1 M NaOH (Valley), 1 M $NaHCO_3$ (ProLab) or 1 M HCl. This water was used for dilution of the suspension to final consistency of ~0.3%. The furnish was left to stand at room temperature over night. Conductivity and pH were checked and adjusted, if necessary, the next day. The suspension was mixed for 1 h before sheet preparation. Sheets (60 g/m^2) were prepared using white water circulation on a sheet former (SCAN-CM 64:00). The sheets were packed in airtight plastic bags and sent within 24 h for wet and dry web measurements. The sheets were pressed using two different pressures (Valley: 0.5 and 3.5 bar, ProLab: 0.5 and 1.5 bar) in order to reach different levels of dry content on the wet handsheets. The handsheets were pressed for 5 + 2 min. Wet handsheets were stored in airtight polyethylene bags at a temperature of 7°C in order to maintain the level of dry content.

Measurements

Fines content

The fibres in the original and in the refined pulp were fractionated according to size in a McNett classifier (SCAN-CM 6:05). 10 g pulp was used in the determination. Wires of 30, 50, 100 and 200 mesh were used. The fibres were collected onto Whatman 589/1 Black Ribbon filter papers, dried and weighed. The <200 fraction passed the 200-mesh wire.

Tensile and relaxation tests

Dynamic tensile strength and relaxation properties of samples from the sheet former were measured with IMPACT, a fast tensile strength testing rig using a strain rate of 1 m/s (1000%/s). The tension holding capability (residual tension) was measured for wet sheets after a fast straining to 2% elongation followed by 0.475 s of relaxation. The width of the test samples was 20 mm (wet samples) and 15 mm (dry samples) and the span length was 100 mm. Before measurements, the samples were attached between two jaws. The lower jaw moved to the desired position creating strain. The upper jaw was equipped with a load sensor. The amount of strain was controlled simply by determining the gap between the lower jaw and target surface. The amount of strain was measured with a laser sensor. In the IMPACT tests, 10-14 samples were measured at each dryness level. The validity of each result was tested using Dixon-Massey criteria (SCAN-G 2:63). For each dry content level, dryness was determined for 4-6 samples using a Mettler Toledo HR73 infrared dryer.

RESULTS AND DISCUSSION

Fines Content

A McNett classifier was used to determine the differences in the original and the refined pulp (Fig. 3).The amount of fines increased with increased degree of refining. The fines were defined as the particles passing through a 100 mesh wire in order to ensure that there was enough small particles. When the Valley beater was used, the amount of fines increased from 2% in the original pulp (SR 20) to 13% in the pulp refined to SR 70. The amount of long fibres decreased only slightly, pulp refining in Valley beater is a mild treatment. When the ProLab refiner was used, the amount of fines increased from 6% (SR 20) to 7% (SR 30) and 13% (SR 70). The pulp that was used for separation of fines (SR 88) had a fines content of 16%. The difference in amount of fines in the original pulps used was due to using two separate batches of the same pulp which were defrosted at separate occasions. The amount of long fibres decreased more when the Prolab refiner was used, indicating that more fibre cutting occurred during refining than during refining with the Valley beater.

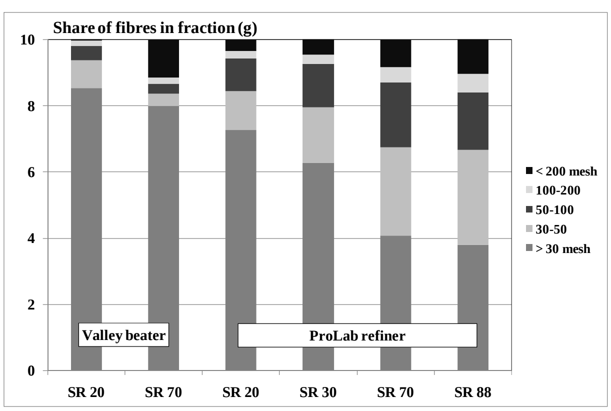


Figure 3. The fibre fractions in the original (SR 20) and the refined pulp determined with a McNett classifier.

Dewatering and Air Permeability

Dewatering time and air permeability were measured with the DDÅA (Table I). Refining of pulp increased the dewatering time with both types of refiners. Refining in Valley beater to SR 70 produced a lot of fines without cutting fibres too much (Fig. 3), which upon web forming resulted in a more packed sheet and longer dewatering time than the original pulp. This was also verified by the decrease in air permeability. Removal of fines resulted in shorter dewatering time and increased air permeability. This kind of phenomenon has been reported previously [13]. Refining of pulp in the ProLab refiner to SR 70 cut the fibres more than the Valley beater, resulting in more evenly distributed size fractions (Fig. 3). During sheet forming, the cut fibres and fines were able to form a more densely packed sheet than the pulp refined in the Valley beater. The dewatering time was therefore much longer and the air permeability lower than for pulp refined in the Valley beater. Removal of fines resulted in dewatering times close to the dewatering time of the original pulp (SR 20). Addition of 15% fines to original pulp prolonged the dewatering time, but not as much as refining to SR 70.

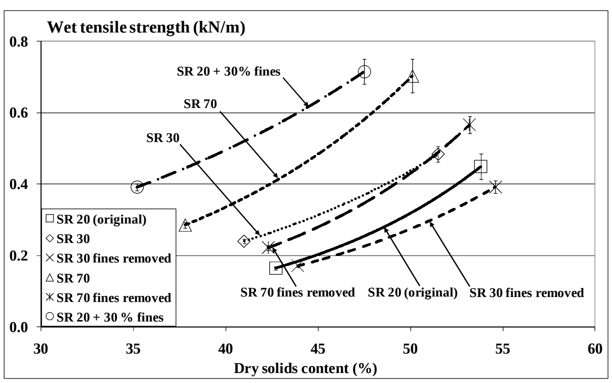
Table I. Dewatering time and air permeability measured with the DDÅA.

	Valley		ProLab	
	Dewatering time (s)	Air permeability (bar)	Dewatering time (s)	Air permeability (bar)
SR 20 (original)	0.7 (± 0.2s)	0.31 (± 0.002)	0.3 (± 0.022)	0.25 (± 0.028)
SR 30	0.9 (± 0.1s)	0.28 (± 0.002)	0.5 (± 0.034)	0.24 (± 0.045)
SR 30 fines removed	*	*	0.2 (± 0.011)	0.27 (± 0.025)
SR 70	3.4 (± 0.1s)	0.24 (± 0.011)	5.0 (± 0.019)	0.17 (± 0.033)
SR 70 fines removed	0.6 (± 0.1s)	0.31 (± 0.016)	0.4 (± 0.048)	0.26 (± 0.029)
SR 20 + 15% fines	*	*	4.5 (± 0.095)	0.22 (± 0.064)

* = not determined

Wet Web Properties

Refining of pulp resulted in increased wet tensile strength at constant dry content (fig. 4). When the Valley beater was used (left in fig. 4), the wet tensile strength increased and the dry content after wet pressing decreased with increased degree of refining. This behaviour has been reported before [14] and fibrillar fines are known to enhance the fibre-fibre bonding [11]. Removal of fines caused a decrease in the wet tensile strength compared to sheets containing the fines. In the case of SR 70 were fines were removed, the tensile strength was higher than the tensile strength for sheets made from the original pulp (SR 20), indicating that the changes in the fibres, e.g. internal and external fibrillation, increased bonding. The dry content after wet pressing was similar to the dry content of the original pulp, which can be explained by the removal of the swollen and water-containing fines. When 30% fines were added to the original pulp, the wet tensile strength increased the most.



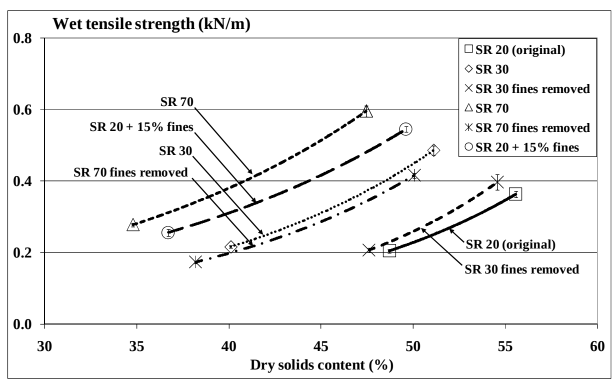


Figure 4. Wet tensile strength after refining, removal of fines or addition of fines. Left: Pulp refined using the Valley beater. The sheets were pressed to two different dry contents (0.5 and 3.5 bar). Right: Pulp refined using the ProLab refiner. The sheets were pressed to two different dry contents (0.5 and 1.5 bar).

When the ProLab refiner was used (right in fig. 4), the results were similar to the results obtained when the Valley beater was used. The wet tensile strength was slightly lower for the SR 70 compared to when the Valley beater was used, which could be due to the shorter fibres formed during the refining (Fig. 3). The dry contents after wet pressing were also slightly lower. Refining in the Prolab refiner is a much harsher treatment than refining in Valley beater, and therefore the fibres were more damaged. The consequence is higher water retention of the fibres [15], which was seen as a lower dry content after wet pressing.

The residual tension describes the tension-holding capability of the paper at constant strain. The residual tension at 2% strain showed similar trends as the results from tensile strength measurements (Fig. 4). The residual tension increased when the pulp was refined (Fig. 5). When the fines were added to original pulp (SR 20), the residual tension at 2% strain did not increase as much as the wet tensile strength did, indicating that the fibre properties are more important for the residual tension than the fines content.

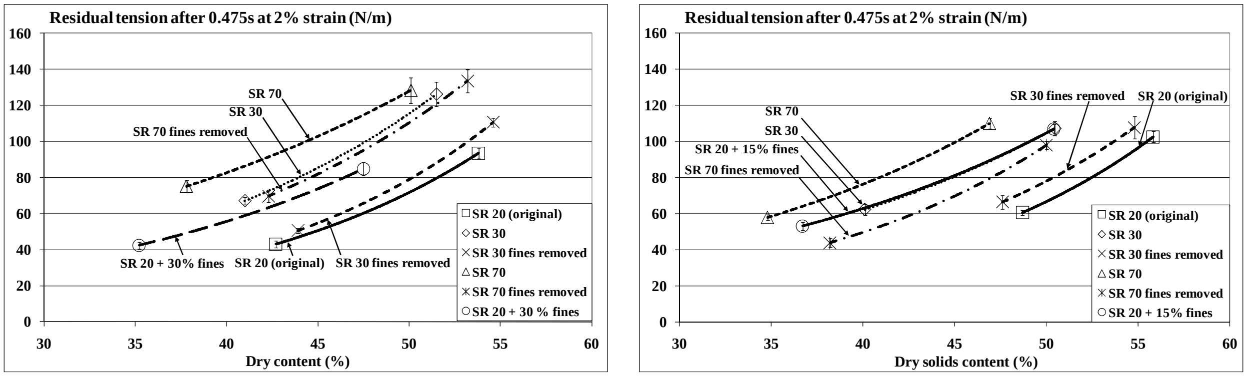


Figure 5. Residual tension at 2% strain after refining, removal of fines or addition of fines. Left: Pulp refined using the Valley beater. The sheets were pressed to two different dry contents (0.5 and 3.5 bar). Right: Pulp refined using the ProLab refiner. The sheets were pressed to two different dry contents (0.5 and 1.5 bar).

Dry Sheet Properties

When tensile index was plotted against density (Fig. 6) it was obvious that both the density and the dry tensile strength increased when the pulp was refined. Fines are known to increase the density and the bonded area of the sheet [9]. The density was somewhat higher when the ProLab beater was used, which could be explained by the shorter fibres formed during the refining (Fig. 3) giving a more densely packed sheet. Removal of fines decreased both the tensile strength and density, the decrease in density was much higher for sheets prepared from ProLab-refined pulp. Addition of fines increased both the tensile strength and the density. Adding fines increases the bonding ability of the pulp [7]. The increase in tensile strength was not as big as the increase in wet tensile strength (Fig. 4).

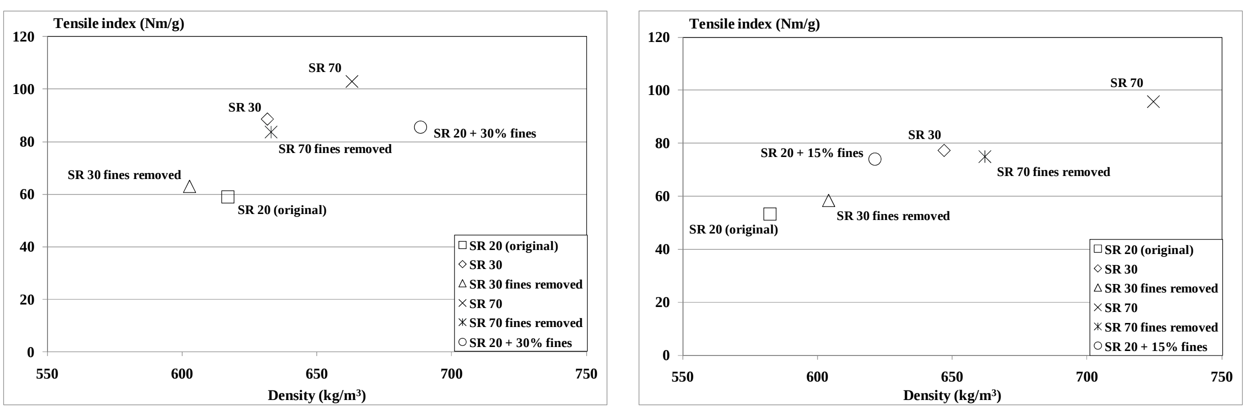


Figure 6. Tensile index vs. density of dry sheets. Left: Pulp refined using the Valley beater. Right: Pulp refined using the ProLab refiner.

CONCLUSIONS

In this study, the effects of fibre properties and fines content on dewatering, dry and wet web properties were studied. Refining using the Valley beater resulted in only a slight decrease in the share of long fibres. The amount of fines was high in the refined pulp, indicating that the majority of the fines were of fibrillar nature peeled off from the fibre wall. Refining using the ProLab refiner resulted in a decrease in the share of long fibres. The generated fines consisted mostly of pieces of fibres derived from the cut fibres.

Refining increased the tensile strength of the wet web. The fines increased the dewatering time and decreased the air permeability due to increased density of the sheet. The bonded area of the sheet was increased by the presence of the fines, giving a higher dry tensile strength as a result.

Removal of fines resulted in decreased wet tensile strength, residual tension, density and dry tensile strength.

Addition of fines to the original pulp resulted in increased wet tensile strength and residual tension, longer dewatering time and increased density and dry tensile strength. The addition increased the bonding ability of the pulp.

Based on the results it can be concluded that fines have a significant impact on the wet and dry web properties. The refining is an important step in improving the mechanical properties of the pulp and paper. The drawback of refining is the longer dewatering, since the amount of fines either added to original pulp or generated though refining prolonged the dewatering time. Therefore efforts will be made to improve the dewatering of refined pulp in the near future.

ACKNOWLEDGEMENTS

Joakim Lind and Johan Isaksson are gratefully thanked for the skilful help with the sheet making and drainage tests. Financial support from the international PhD programme in Pulp and Paper Science and Technology in Finland (PaPSaT), Finnish Funding Agency for Technology and Innovation (TEKES), Kemira Oyj, Metso Paperi Oy, Stora Enso Oyj and UPM-Kymmene Oyj is gratefully acknowledged. This work is part of the activities at the Åbo Akademi Process Chemistry Centre within the Finnish Centre of Excellence Programme 2006-2011.

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