Determination of Repulpability of Talc-Filled Biopolymer Dispersion Coatings and Optimization of Repulped Reject for Improved Material Efficiency by Tailoring Coatings

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ABSTRACT

Traditional synthetic-polymer-based dispersion coatings are generally considered repulpable, but the repulpability of composite-type, highly bio-based dispersion coatings have been studied less. In this study it was found that the amount of reject after sieving of repulped biopolymer-coated paperboard was up to 50%. This indicates that the material loss can be significant, and new approaches are thus needed for utilizing the vast amount of reject. In order to clarify the effect of coating composition on the amount of reject, paperboard coated with either hydroxypropylated starch (HPS) or hydroxypropyl-cellulose (HPC) and different proportions of talc and styrene-butadiene latex binder were prepared and analysed. It was revealed that repulpability of paperboards coated with HPC-based dispersions was poorer than that of HPS-coated ones. Interestingly, the presence of talc improved the repulpability of HPC-coated boards, but similar effect was not detected from samples whose main coating component was HPS, which was ascribed to poorer dissolving of HPS at low temperatures that assisted in keeping the talc particles bound in starch. Therefore, we studied the possibility to re-utilize dispersion-coated reject as a raw material in paperboard production. The formation of the handsheets containing reject was only slightly impaired by a 5% addition level, but increasing the proportion of reject to 15% led to a 20% increase in formation due to large flocks originated from the coated broke. Chemical properties of reject was also discussed in terms of e.g. zeta-potential. Physical properties were also determined. Reject addition decreased the air permeance of the handsheets moderately regardless of whether the source of the reject was coated or uncoated board. Moreover, the results suggested that HPC-containing reject may slightly increase bulk. The results implied that the repulpability of dispersion-coated paperboard is highly dependent on the pulpability of the base board, but there are no particular hindrances to re-utilize small amounts of dispersion-coated board reject in board manufacturing in terms of physical properties of the paperboard.

INTRODUCTION

Increasing environmental concerns over the use of polymeric extrusion coatings have increased the general interest in applying barrier dispersion coatings on a paperboard. Dispersion coatings can be repulped, composted or burned at a waste burning plant [1], indicating that the dispersion coating has certain benefits compared to plastic extrusion coatings. Aqueous dispersions used for barrier coating can be based on synthetic polymers or biopolymers, but also on their mixtures. Mixing of a hydroxypropylated starch (HPS) with inorganic pigments and synthetic polymers has been reported to render good grease barrier properties [2, 3]. In addition, several other attempts to use bio-based coatings as barriers have been reported recently [4−7]. Another promising component for dispersion coating is hydroxypropyl-cellulose (HPC), which is the only edible film-forming thermoplastic and biodegradable cellulose derivative [8]. A recent study showed that the convertability of paperboard coated with HPC-based dispersions is

superior to e.g. polyethylene terephthalate coatings, but more optimization should be done in order to improve the barrier properties of HPC-based coatings [9].
There are several sources of coated broke, such as trimmings and bottoms of rolls, but also the runnability of the paper and coating machines affect the amount of arisen broke. Repulpability of dispersion-coated board depends on several factors including the thickness of the coating layer, the existence of pre-coating, the proportion of hydrophobic components such as insoluble binders in the coating and the coalescence of the polymeric particles [1]. The repulpability of latex-based coatings can be improved by adding inorganic minerals in the coating dispersion, since the presence of pigments assists to obtain smaller particles as a result of the repulping process [10]. Inorganic minerals originated from coated broke have also been reported to decrease the blocking tendency of sheets in laboratory conditions [10]. However, repulpability itself does not guarantee that the dispersion-coated material can be used successfully again in papermaking process [1]. From the viewpoint of papermaking, it is optimal that the zeta potential of the wet-end, comprising the charge of fiber surface and solute compounds, is close to zero [11, 12], but accumulation of dirt on the wires should be prevented in order to maintain the runnability and to prevent formation of holes in paper. Another typical cause of holes in web is the weakly-bonded agglomerated latex particles. The agglomeration of latex, however, can be controlled by adding talc, which adsorbs on sticky surfaces of loose latex particles [13].

Even though the repulpability of dispersion coatings based on synthetic polymers has been studied widely, there is a lack of understanding the repulpability of bio-based dispersion barrier coatings, such as hydroxypropylated starch-based approaches [3]. The main use of starch in papermaking is surface sizing [14], and from that point of view the effects of starch originated from broke on paper chemistry has been studied widely. Negatively charged oxidized starches act as anionic trash, causing retention problems in wet-end and further increase the demand of cationic fixing agents and those, contrary to cationic starches, may also impair the optical properties and printability of produced paper [15, 16]. Starch originated from coated broke can be considered as relatively undispersed, and this can actually be beneficial if the stock contains unbeaten or slightly beaten pulp, since the large starch granules in a low-density sheet aids the formation of interfiber bonds [17], which improves the strength properties of the web.

There are only very few publications of the effect of repulping conditions on the repulpability and the usability of coated broke in paper manufacturing. It has been shown that alkaline conditions or low temperature in repulping stage improve the tensile strength of sheets containing broke. In addition, optimization of the temperature of the repulping process should be considered, since it has influence on the large particle fraction and it can decrease the tensile strength of produced paper. [10]

According to our knowledge, the major lack of determining the repulpability of dispersion-coated papers and boards is that there is no official standard procedure for carrying out the measurement. The best available method is the voluntary standard for repulping and recycling corrugated paperboard [18]. The undeniable benefit of this voluntary standard is that the determination can be carried out with typical instruments of a papermaking laboratory. Based on the interpretation of Michelman Inc. [19], the sample with an aqueous coating passes the repulpability test if the percentage of reject is less than 15.

In this study the repulpability of dispersion-coated boards with high content of bio-based coating components was investigated. The dispersion coatings studied consisted of hydroxypropylated starch or hydroxypropyl-cellulose, SB-latex and talc. Furthermore, handsheets were prepared with different proportions of reject from laboratory-scale repulpability test, and the handsheet properties, such as air permeability, formation, tensile strength and gloss were examined and compared.

EXPERIMENTAL

Materials

Two reference samples, i. uncoated solid bleached sulphate paperboard with a grammage of 350 g/m^2 (Ref. 1, Trayforma Natura, Stora Enso Oyj, Imatra, Finland) and ii. bleached cup board blade-coated with polyolefin dispersion Hypod™ 8501 (Ref. 2, Dow Chemical Company) with a grammage of 220 g/m^2 (Cupforma 210, Stora

Enso Oyj, Imatra, Finland) were used throughout this work. The latter reference simulated a commercial barrier-dispersion-coated product.

Two biopolymers, hydroxypropyl-cellulose (Klucel™ J-Ind, Ashland Inc.) and low-viscous potato-based hydroxypropylated starch (Solcoat P55, Solam GmbH, Germany), were used as main components of coating dispersions. Dispersed barrier grade talc (Finntalc C15B, Mondo Minerals B. V., Finland) was used in combination with the biopolymers. Aspect ratio (quotient of the largest diameter and the smallest diameter) of the talc was characterized with a Malvern Morphologi G3 instrument. The sample had a bimodal particle size distribution (peaks approx. 2 µm and 20 µm). The largest particles were platy (diameter >10 µm), but there were also small needle-like objects (approx. 0.2-2.0 µm) resulting in a very wide aspect ratio distribution with an average value of 0.6. Coating dispersions were prepared with and without the addition of latex. The latex (Styron HPW-184, Styron Europe GmbH) with a glass transition temperature of -9°C was an experimental product based on styrene-butadiene (SB). The mean particle size of the latex was measured with a Malvern Zetasizer Nano ZS instrument (Malvern Instruments Ltd.) to 160 nm. The compositions of the coating dispersions are shown in Table I. The latex addition was calculated on the basis of the total dry matter content of the other components, talc and biopolymer. The test points containing both latex and talc were prepared by first blending latex and talc together and then mixing with HPS.

Table I. Compositions (pph) of the coating dispersions.

	Coating dispersion No.						
Component	**1**	**2**	**3**	**4**	**5**	**6**	**Ref. 2**
Hypod 4501	-	-	-	-	-	-	100
Solcoat P55	100	75	75	-	-	-	-
Klucel J-Ind	-	-	-	100	75	75	-
Finntalc C15B	-	25	25	-	25	25	-
Styron HPW-184	-	-	10	-	-	15	-

The targeted dry solids content of the dispersions, which was measured using a precision balance equipped with an infrared dryer (mass of sample 0.5 g, drying temperature 105°C), was 16.5 wt% in the case of HPS containing dispersions. HPC-based dispersions were prepared to 10% solids content due to high viscosity of HPC. The test points containing both latex and talc were prepared by first blending latex and talc together and then mixing with HPS or HPC. The dry solids content of Hypod dispersion was 45%.

Pilot coating

A4 sheets of Ref. 1 was used as a base substrate for all experimental dispersions 1-6. The sheets were double-coated with a bent-blade coater system in a pilot coater from DT Paper Sciences Oy, Turku, Finland. Layout of the bent-blade coater system is presented in the Figure 1. The hard-tipped blade angle was adjusted continuously in order to obtain the targeted coat weight, 5 g/m^2/layer, accurately. The coating dispersion was applied with the roll applicator, the machine speed during the coating was 10 m/min and blade pressure 1.4 – 1.7 bar. The total coat weight was thus 10 g/m^2. Coated samples were dried with an infrared dryer with a heating power of 6 kW. The drying time was 8−12 seconds depending on the proportion of pigment of the coating dispersion.

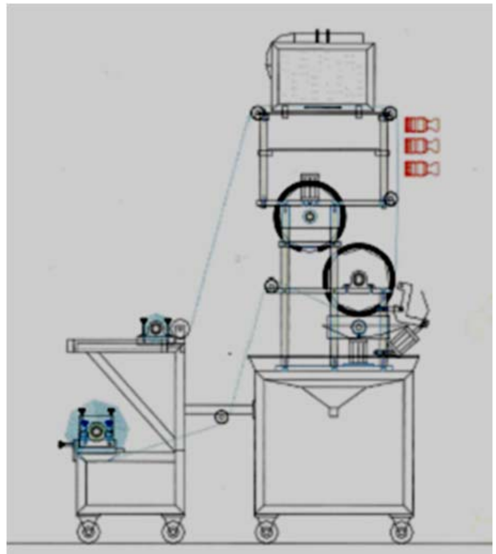

Figure 1. Layout of the bent-blade coater system (DT Paper Sciences Oy, Finland).

Oil and grease resistance (OGR) of coated paperboards were determined according to ISO 16532-1 using palm kernel oil with a Sudan red dye as a reagent. The average value of the show through time (lower limit of the time interval described in the standard was used in the calculation) of uncreased samples was reported. As shown in Table II, none of the bio-based coatings provided as good grease resistance as Ref.2 material, but especially samples coated with HPS-based dispersions showed moderate grease barrier properties regardless of the presence of talc or latex. HPC-based coatings let the grease penetrate through the material very fast, which was ascribed to the tendency of HPC coatings to have pinholes [9]. An addition of talc, however, was found to be beneficial also in the case of HPC-based coatings.

Table II. Oil and grease resistance (min) of coated experimental materials.

	Coating composition, [pph]						
	HPS 100	**HPS:talc 75:25**	**HPS:talc:latex 75:25:10**	**HPC 100**	**HPC:talc 75:25**	**HPC:talc:latex 75:25:10**	**Ref. 2**
Coat weight, [g/m^2]	8.0	7.5	7.5	9.0	7.0	6.5	10.0
OGR, [min]	180	180	258	2	56	4	360
St. Dev.	±0	±0	±57	±1	±28	±1	±0

Repulping procedure

To investigate the repulpability of coated board, FBA's method [18] with minor modifications was used. The determination was carried out by ripping 100 g of the paperboard in pieces (approx. 2.5 cm x 2.5 cm). Ripped paperboard pieces were soaked in water at room temperature for at least four hours. The pieces were disintegrated with a L&W Pulp Disintegrator ("British disintegrator", Lorentzen & Wettre, Sweden) with a presence of water at an initial temperature of 52°C and at a consistency of 5% (V_{tot} 2000 ml, 10 000 revolutions). After disintegration, the pulp slurry was mixed with a post-type mixer for four minutes. The mixed slurry was filtrated for 20 minutes with a Somerville type screen fractionator (Lorentzen & Wettre, Sweden) with a water pressure of 1.25 bar and a water temperature of 40°C. Percentual amount of reject was calculated based on the initial dry mass of the disintegrated slurry and the fibers that were collected from the sieve after fractionation and whose dry mass was determined by drying the fibers in an oven overnight (105°C). Based on Michelman, Inc., material with a reject content of smaller than 15% passes the test and can be considered as repulpable [19].Three parallel separations were made for each paperboard sample, including both reference boards. The zeta-potential of the reject was determined with a Mütek SZP-06 instrument. The average value of three independent measurements was reported.

Evaluation of broke storing time on its electrochemical properties

Electrochemical properties of repulped coated broke with polymeric coatings were assessed by zeta-potential and conductivity determinations (Mütek SZP-06, BTG Instruments AB, Sweden), charge determination (Mütek PCD-02, BTG Instruments AB, Sweden), and pH measurement after 0, 6, 24, 48, 72 and 96 hours after repulping. Three parallel measurements were carried out in all cases and the average value and its standard deviation were reported. The samples chosen for repulping were i.) uncoated Ref. 1, ii.) Ref. 1 paperboard coated with a blend of HPS and latex (90:10), and iii.) Ref. 1 coated with a blend of HPC and latex (85:15). Talc-containing broke was not tested due to the adsorbent properties of talc. Repulping was carried out as described in previous chapter without the sieving process. The broke was stored in room temperature during the test period.

Preparation and testing of reject-containing laboratory handsheets

Laboratory handsheets (60 g/m^2) were prepared from disintegrated Ref. 1 paperboard with reject contents of 0, 5, and 15% in accordance of ISO 5269-1:2005. The grammage of the sheets was determined in accordance with ISO 536:2012. Thickness (ISO 534:2011) was measured in order to calculate the sample bulk. Formation was determined following SCAN-P 92:09 with a beta formation tester (Ambertec, Finland) and the formation values normalized with the sheet grammage were reported. Formation was also analyzed with beta radiography and phosphor storage screen imaging [20]. We have used a Formex Box unit from Science Imaging Scandinavia AB for imaging, a Fuji BAS-MS2025 imaging plate and a Fuji BAS1800 II scanner. Exposure time was 6800 seconds, leading to a PSL level of 30. The formation images had a spatial resolution of 50µm / pixel. For quantitative analysis the images were FFT low-pass filtered for wavelengths larger than 0.25mm. The coefficient of variation (COV) in the band pass filtered images is reported as a measure for the degree of flocculation.

Air permeance of the sheets was determined with a Bendtsen tester (Lorentzen & Wettre, Sweden). Stiffness determination was carried out in accordance with ISO 5628:2012. Tensile strength was determined with an L&W Tensile tester (Lorentzen & Wettre, Sweden) in accordance with ISO 1924-3:2005. Z-strength was tested on the repulped handsheets according to Tappi standard T541 om 05. Ten specimen were tested for each paper.

RESULTS AND DISCUSSION

Colloidal stability of repulped broke

The changes in electrochemical properties of repulped broke are presented in Table III. Uncoated sample (Ref. 1) experienced smaller alterations than samples containing HPS and latex or HPC and latex. Uncoated broke (Ref. 1) was less anionic than coated brokes. The charge remained in the same range during the 96 h test period, although HPS-based broke was a little more instable than uncoated broke and HPC-based broke. Conductivity of all brokes increased during the period. In the case of HPS-based broke, the increase was slight compared to uncoated broke and HPC-coated broke. Moreover, decreased pH values were observed in all cases, but the change was not drastic. Zeta-potential of uncoated broke and HPS-based broke decreased during the test period, indicating increased stability, but a modest increase in zeta-potential of HPC-containing broke was observed. Since no major changes in electrochemical properties of brokes were found, it can be supposed that the coated broke remains usable for several days in room temperature without a presence of biocides.

Table III. Charge, conductivity and zeta-potential of repulped coated broke immediately after repulping and after 24, 48, 72 and 96 hours.

Sample	Charge, [meq/g]	Conductivity, [mS/cm]	pH	Zeta-potential, [mV]
Ref. 1				
0 h	-43.2±3.4	0.044±0.002	8.0	-137.3±1.6
24 h	-40.0±1.8	0.056±0.003	8.2	-134.4±1.1
48 h	-39.8±2.3	0.057±0.003	7.8	-150.4±0.6
72 h	-36.4±0	0.055±0.001	7.5	-143.3±2.2
96 h	-45.9±1.0	0.063±0.001	7.7	-151.3±2.0
HPS:latex 90:10				
0 h	-93.5±2.7	0.078±0	8.2	-85.5±0.2
24 h	-	0.086±0.001	7.7	-99.4±0.6
48 h	-84.2±0.5	0.089±0.001	7.1	-100.8±4.9
72 h	-84.5±2.4	0.090±0	7.1	-95.7±2.5
96 h	-105.9±7.7	0.089±0.001	7.3	-96.8±0.1
HPC+latex 85:15				
0 h	-	0.042±0.001	8.0	-110.9±2.5
24 h	-100.6±2.9	0.062±0.001	7.6	-114.1±4.4
48 h	-97.6±4.7	0.061±0	7.6	-111.6±1.6
72 h	-96.4±0.7	0.060±0.003	7.7	-108.1±4.7
96 h	-93.8±1.0	0.060±0	7.6	-96.9±1.6

Repulpability of dispersion-coated boards

Figure 1A shows the general appearance of reject on the sieve. Some of the flocks from dispersion-coated broke had a diameter of 5 mm (Figure 1B). In addition, smaller flocks were found from the reject of uncoated reference paperboard (Ref. 1). Based on the images, it is obvious that the coating was not the only reason behind the high reject percentage, but also the used paperboard was quite challenging product in terms of its repulpability.

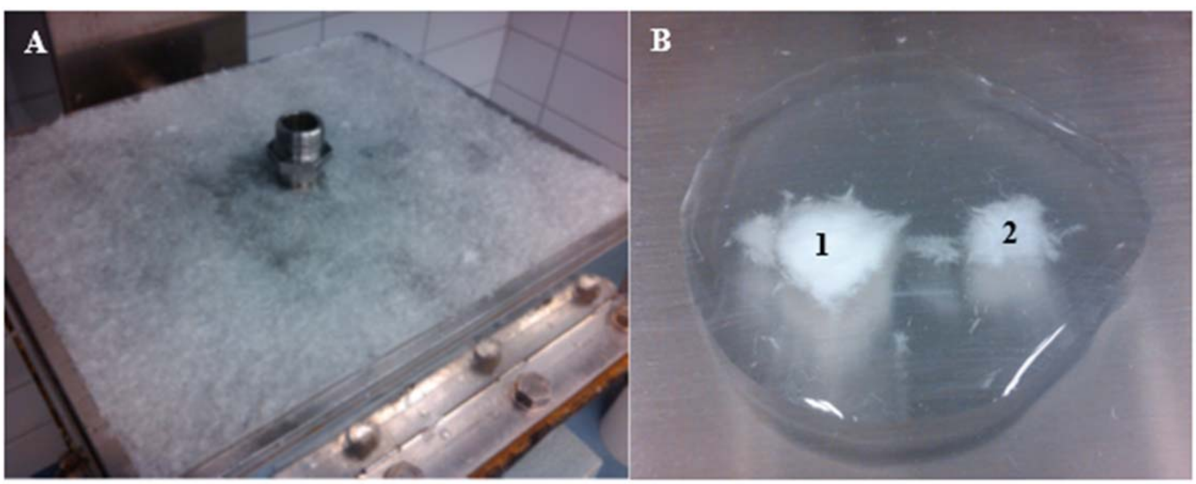

Figure 1. Reject from sample #3 on the Somerville sieve (A), an example of a reject flock with coating on the surface (B-1), and a regular fiber flock (B-2).

The percentage of reject after fractionation with a Somerville-type sieve and the zeta-potential of the reject are presented in Table IV. The repulpability of Ref. 2, which simulated a commercial dispersion-coated sample, was excellent compared to uncoated reference (Ref. 1) and all the experimental coatings. The amount of reject from HPS-based coatings was approximately 30%, whereas substantially higher proportions were detected from HPC-based coatings. The presence of talc, however, decreased the amount of reject from HPC-based coatings but similar effect was not found if the coating contained HPS. This was ascribed to poorer solubility of HPS, which probably assisted in binding the talc particles in the starch matrix. If latex was present, the amount of reject slightly increased in the case of both biopolymers, but reliable conclusions cannot be made due to the inaccuracy of the measurement. An interesting observation was that only Ref. 2 fulfilled the definition of a repulpable material set by Michelman Inc. [19]. This finding emphasizes also the importance of the selection of base board in the development of dispersion-coated papers and paperboards.

The zeta-potential of the uncoated reference (Ref. 1) was -57.7 mV, indicating that the system was highly stable and anionic. The zeta-potentials of the rejects from experimental samples were notably higher, indicating increased instability of the system. HPC increased the zeta-potential of the reject more than HPS. Interestingly, talc and latex helped to maintain the zeta-potential of HPS-based coatings, but their effect was opposite in HPC-based reject. This was ascribed to better solubility of HPC into water at lower temperatures. From the viewpoint of papermaking process, having a zeta-potential close to zero is beneficial [11], and thus the utilization of repulped board in the board manufacturing is in principle useful.

Table IV. Percentual reject from reference and experimental samples and the zeta-potential (mV) of the repulped reject.

Sample	Reject, [%]	Standard deviation	Zeta-potential, [mV]	Standard deviation
Ref. 1	18.2	2.2	-57.7	4.4
Ref. 2	2.9	0.6	*	*
HPS	27.2	1.3	-33.7	8.1
HPS/talc	30.9	3.0	-38.9	1.6
HPS/talc/latex	32.0	4.2	-35.8	8.6
HPC	54.3	11.1	-28.0	1.4
HPC/talc	42.7	2.1	-22.3	3.6
HPC/talc/latex	44.1	7.0	-19.9	4.6

* Measurement did not succeed due to very low obtained reject amount

Physical properties of the reject-containing handsheets

Table V shows the physical properties and the normalised formation of handsheets with different reject contents. Obtaining the targeted grammage was awkward due to high number of flocks in the pulp suspension. Uncoated broke reject had only a minor influence on bulk, but HPS- and HPC/talc-coatings decreased the bulk moderately. As for HPC-containing reject, a 5% addition increased the bulk, which is definitely beneficial in the case of paperboard manufacturing, but a larger share again resulted in bulk loss. The minor decrease in bulk noticed from HPS coating was ascribed to poorly dispersed broke-originated starch due to mild repulping temperature, which did not close the network consisting of slightly beaten pulp effectively by excessive bonding. Introducing latex in the coating, however, interestingly aided to control the bulk loss regardless of the addition level of the reject. It is plausible that latex was at least partly bonded with talc [13], and the resulting agglomerates caused local density variation and thus more bulky regions in the sheet. This aspect was also supported by the normalized formation values of sheets containing 15% of reject. In general, adding reject from uncoated reference material improved the formation, but the presence of HPS caused slightly poorer formation.

Table V. Grammage, density, bulk and normalized formation of laboratory handsheets (target: 60 g/m^2) with 5% and 15% of added repulped reject.

Sample	Grammage, [g/m^2]	Density, [kg/m^3]	Bulk, [cm^3/g]	Formation, [√gsm]
Ref. 1				
0%	65.0	631	1.60	1.7
5%	55.5	582	1.72	1.5
15%	66.5	626	1.60	1.4
Ref. 2				
5%	66.0	656	1.52	1.5
15%	67.5	650	1.54	1.7
HPS				
5%	67.0	642	1.56	1.8
15%	67.0	642	1.56	1.9
HPS/talc				
5%	61.0	681	1.47	1.9
15%	69.0	650	1.54	1.4
HPS/talc/latex				
5%	65.0	631	1.56	1.5
15%	65.0	619	1.62	1.8
HPC				
5%	62.0	557	1.80	1.6
15%	64.0	687	1.46	1.8
HPC/talc				
5%	65.5	637	1.57	1.7
15%	67.5	698	1.43	1.6
HPC/talc/latex				
5%	69.0	575	1.74	1.7
15%	69.0	643	1.55	1.7

Formation was also estimated visually in order to achieve more detailed information of flocs present in handsheets (Figure 2). Handsheets containing uncoated reject (Ref. 1) appeared relatively similar regardless of the reject content. Their formation (CoV > 0.25 mm: 0.067 with 5% reject addition; 0.064 with 15% addition) was close to Ref. 2 samples (CoV > 0.25 mm: 0.068 with 5% reject addition; 0.072 with 15% addition). Samples containing reject from HPS-coated board had a poorer formation compared to handsheets containing uncoated reject (CoV > 0.25 mm: 0.072 with 5% reject addition; 0.076 with 15% addition), although the values did not drastically differ from those of handsheets containing 15% of Ref. 2 reject. Handsheets containing HPC-based reject, however, appeared to be the poorest ones when it comes to formation. Visual observation revealed dense flocs that were substantially large with 15% addition level, and this was also reflected to numerical formation values. For instance, if the reject contained residues of HPC, talc and latex, the coefficient of variation (> 0.25 mm) was 0.076. With the poorest sample (HPC/talc 15%; not shown here), the coefficient of variation was 0.089. The detrimental effect of talc and biopolymer blend was also seen in the case of HPS, but the presence of latex in the system reduced the tendency of talc to impair the formation. This suggests that talc collects and binds biopolymer deposits effectively and that leads to an emergence of large flocs that impair handsheet formation. Since the problem was smaller if latex was present, preferential adsorption of hydrophobic polymers seemed to take place, and this suggests that dual-polymer reject is not as detrimental to formation of produced handsheets.

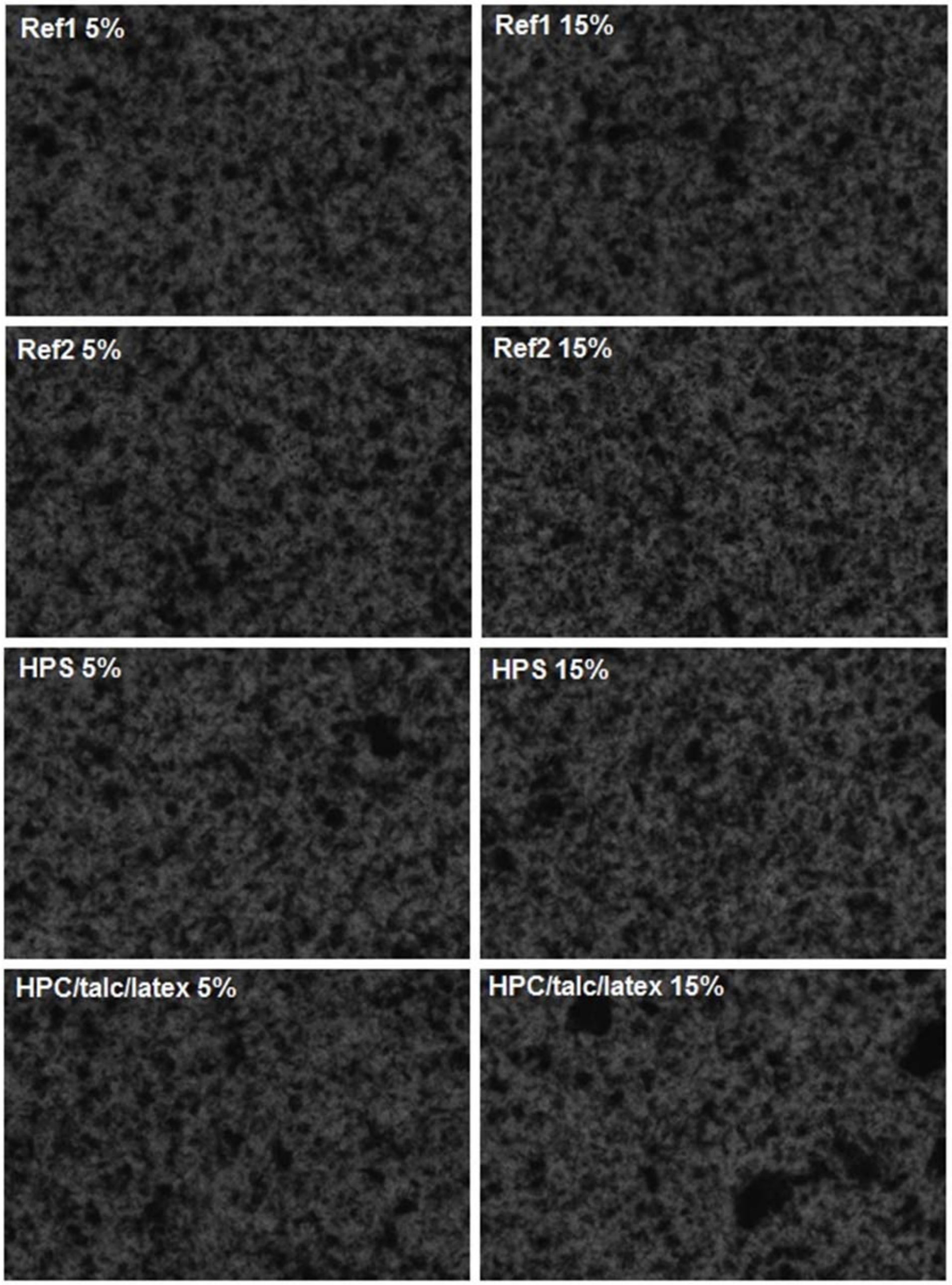

Figure 2. Examples of floc structures in handsheets. Size of the image is 90 mm x 60 mm.

Air permeance of reject-containing handsheets

Figures 3-4 show the air permeance of the reject-containing handsheets with different reject proportions. The changes were mostly very minor and standard deviations made it difficult to draw reliable conclusions. For comparison, with broke of Ref. 2, the air permeance was 55.5±2.4 ml/min with 5% reject content, and 53.7±1.5 ml/min with higher reject amount. Compared to handsheets made from repulped Ref. 1 without reject, a moderate decrease in permeability was found. In case of HPS-based reject, the presence of talc led to the smallest air permeance, but this result cannot be considered reliable due to large standard deviation. Latex, however, seemed to have a reverse effect, especially if the reject content was 15%. The results were similar in the case of HPC-containing reject as far as biopolymer and talc is concerned, but the combination of HPC, talc and latex had the lowest air permeance. Adding reject from uncoated broke to pulp slurry also slightly decreased the air permeance, probably due to additives from the board. It is highly plausible that biopolymers from the coated broke acted as wet end additives that are known to reduce the air permeance [21] and talc acted as a filler that increased the tortuosity of the sheets.

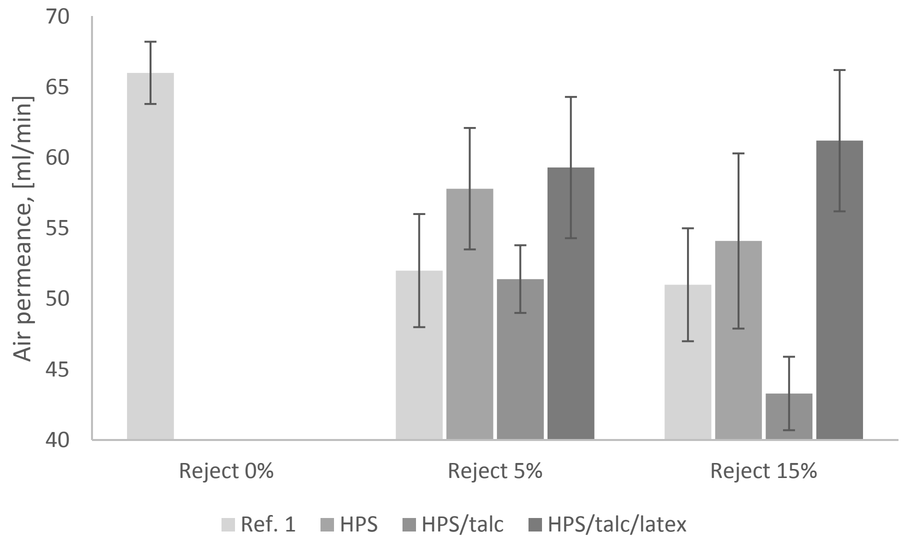

Figure 3. Air permeance (ml/min) of handsheets containing reject from hydroxypropylated-starch-coated boards.

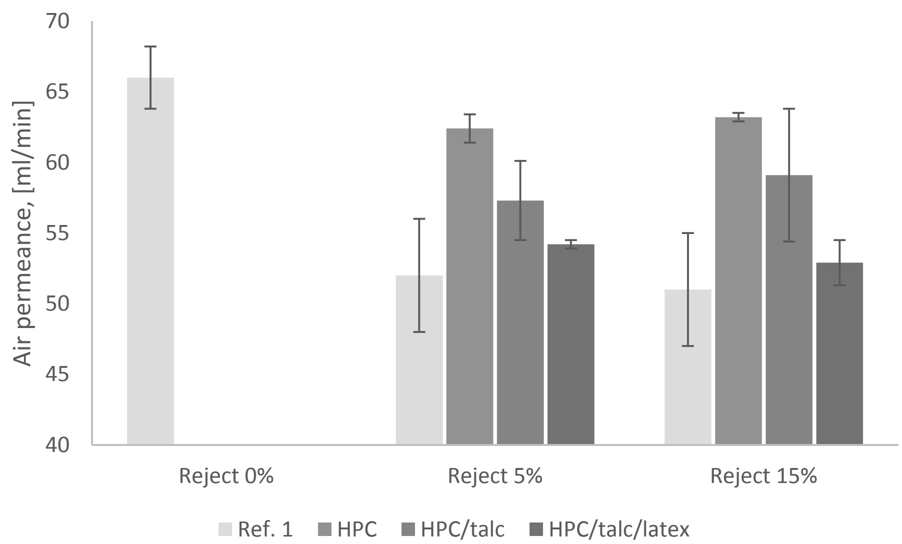

Figure 4. Air permeance (ml/min) of handsheets containing reject from hydroxypropyl-cellulose-coated board.

Effect of coated reject content on strength properties

The tensile index of reject-containing handsheets was relatively similar (21-25 Nm/g with HPS-containing rejects, 18-22 Nm/g with HPC-containing rejects) regardless of the amount of reject or the composition of repulped broke. Without an addition of reject, the tensile index was 23 Nm/g. Both biopolymers slightly decreased the tensile strength if talc residues were not present. The presence of talc helped to maintain the tensile properties, which suggests that talc might bind deposits and thus increase the rate of interfiber bonds. However, the effect of poor formation on tensile strength cannot be ruled out [22], since it was evident that better formation led to stronger paper particularly with 15% reject content in the case of HPS-containing samples. Similar trend was observed also with HPC, although the standard deviation of tensile strength made it difficult to draw reliable conclusions on the linkage between handsheet formation and tensile index. For comparison, the tensile strength of Ref. 2 broke containing materials was close to 21 Nm/g, indicating that the sample simulating commercial dispersion-coated board and experimental materials with biopolymers give a rather similar tensile properties if used as a broke in paperboard manufacturing process. The results thus suggest that HPS-containing broke can be used successfully in the papermaking process without impairing the strength properties of the paper, particularly if talc is present, but the utilization of HPC-coated broke should be limited to small dosages. Bearing in mind that the tensile strength of sheets made from repulped paper (coated with synthetic polymers with and without filling) can be adjusted by optimizing the repulping time, pH in disintegration process and pulp temperature during the disintegration [10], it might even be possible to increase the feed of repulped material in the wet-end without compromising the tensile properties.

Since beta formation of the samples varied moderately and probably disturbed the tensile strength tests, z-directional strength of the handsheets were determined in order to eliminate the effect of formation on the strength properties (Figure 5). Mostly only minor differences between the samples were found and the standard deviations of the measurements made it difficult to distinguish differences between the samples in many cases. Increase in the amount of uncoated reject (Ref. 1) decreased the z-directional strength, but the amount of reject had not influence in the case of coated reference material (Ref. 2). A minor increase in the z-directional strength was observed if the amount of reject from HPS-coated board was increased from 5% to 15%. The combination of HPS and talc, however, increased the z-directional strength moderately, but a mixture of HPS, talc and latex residues did not provide as great increase. The increase in z-directional strength of handsheets containing HPS-based residues was expected, since it has earlier been reported that undispersed starch granules in a low-density sheet may improve the strength properties of paper [17]. Since talc can adsorb cellulose derivatives to some extent [23] and it also binds deposits and sticky substances such as latices, it seems possible that latex residues prevents the capability of talc remains to assist the formation of bonding between fibers. Interestingly, the z-directional strength of handsheets containing HPC was very similar regardless of the reject addition level. This was ascribed to non-ionic nature of HPC that did not promote the formation of interfiber bonds and the possibility that HPC was adsorbed on talc surfaces hiding the capability of talc to promote interfiber bonding by collecting disturbing deposits.

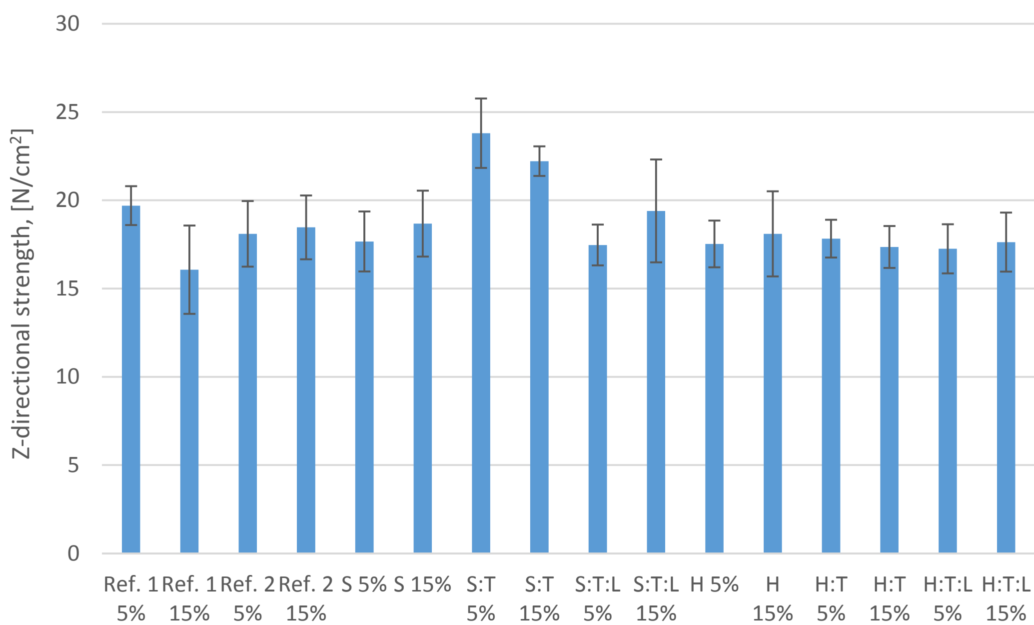

Figure 5. Z-directional strength (N/cm^2) of reject-containing handsheets. S denotes hydroxypropylated starch, T talc, L latex and H hydroxypropyl cellulose.

Effect of coated reject addition to bending stiffness

Effect of reject addition on the bending stiffness of handsheets is shown in Figure 6. The stiffness of handsheets containing uncoated reject (Ref. 1) increased substantially with an addition level of 15%. This was ascribed to an increase in the number of big flocks (see Figure 2) that probably caused local differences in stiffness. Minor increase was also observed if the handsheet contained reject from HPS-coated board or HPC-coated board. The mixtures of HPS and talc or HPC and talc both led to an increase in bending stiffness with 15% addition level compared to pure HPS or pure HPC rejects, but the change was not unambiguous with the 5% reject addition. It also seems that the presence of latex residues results in greater bending stiffness if the reject is HPC-based. However, the standard deviation of the results makes it difficult to make reliable comparisons between the most of the test points.

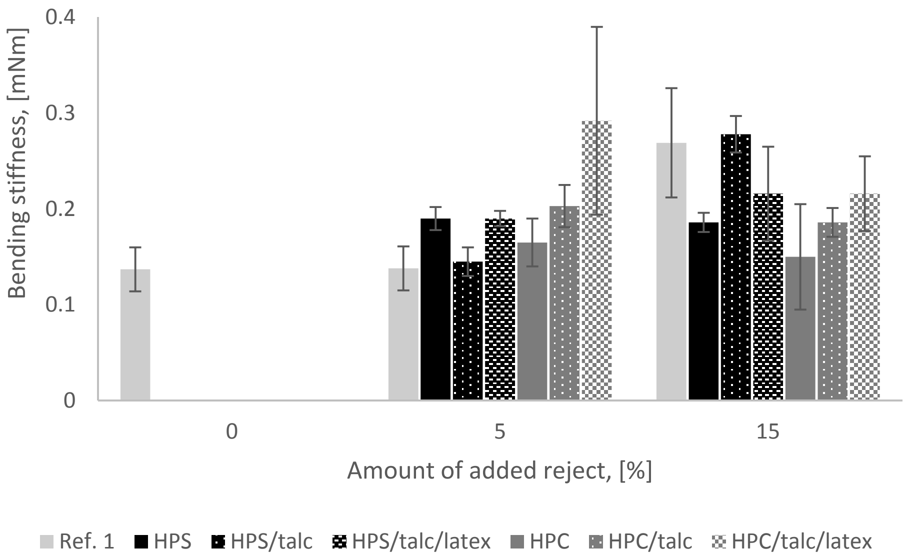

Figure 6. Bending stiffness (mNm) of the handsheets.

CONCLUSIONS

The repulpability of dispersion-coated boards with high content of bio-based coating components was relatively poor compared to sample that simulated a commercial dispersion-coated material. This suggests that dispersion-coated paperboards are easily repulpable only if the coating comprises synthetic polymers, although differences in reject proportion were noticed between HPS and HPC. In addition, the partial replacement of biopolymers with talc did not improve the repulpability of HPS, whereas a minor improvement was observed with paperboards whose coating contained HPC. The utilization of broke in paperboard manufacturing process, however, might be beneficial from the viewpoint of wet-end chemistry, since the zeta-potential of the reject was closer to zero than that of uncoated broke. This implies that the runnability of the board machine could even be improved by broke addition.

The laboratory handsheets with different proportions of reject from repulped coated boards had relatively similar properties as the reject-free reference. Minor decrease in air permeance and tensile strength was found. The probable cause for the observed slight decrease in tensile properties was impaired sheet formation, which was originated from the large flocks in the reject. On the other hand, the handsheets with reject from coated broke showed very high gloss. Results thus suggest that although the repulpability of dispersion-coated broke can be poor, there are no major hindrances to use the broke again in the manufacturing process of paperboard in terms of paperboard properties. This study, however, leaves a topic for optimizing the process conditions such as temperature for bio-based coatings, since the solubility of HPS and HPC are probably affected by the slurry temperature.

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