Improved quality of SC magazine paper through enhanced fibre development using the ATMP process

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KEYWORDS: ATMP, Refiner Bleaching, Energy Reduction, SC paper, Fibre Roughening

SUMMARY: A pilot scale refining trial was conducted using the ATMP (Advanced Thermomechanical Pulp) refining concept with White spruce as raw material. Low-intensity TMP and high-intensity TMP with mechanical pre-treatment of chips were compared to ATMP (Mg+P), where development of fibres was enhanced using hydrogen peroxide and magnesium hydroxide. The main goal of the trial was to evaluate the potential of using ATMP process for production of SC (supercalendered) magazine paper. SC paper is especially demanding when it comes to the paper surface structure which is strongly influenced by the development of fibre properties.

Improvement in individual fibre properties such as flexibility, fibre split index and fibre surface area index achieved using ATMP process was found to translate into decreased surface roughness and air permeability of calendered laboratory sheets. Both the refining process configuration and the addition of process chemicals were found to have significant impacts though the process configuration had major role. The influence of process chemicals on surface roughness was mainly pronounced after second stage refining. The magnitude of surface roughening (fibre rising) was found to be influenced mainly by the process configuration.

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ATMP refining process concept was described earlier (Hill et al. 2009, 2010, Johansson et al. 2011, Gorski et al. 2011a, 2011b, 2012). It combines several process modifications compared to the conventional low-intensity TMP process:

- Defibrating mechanical pre-treatment of chips in Impressafiner and Fiberizer
- Introduction of process chemicals to fiberized chips (after defibration)
- Elevated first stage refining intensity (achieved using feeding segment pattern and/or higher rotational speed of the refiner)

Pilot scale ATMP trials on *Pinus taeda* indicated an improvement in electrical energy efficiency with up to 1.1 MWh/odt or 42% at tensile index 25 N.m/g and brightness of the pulp increased with 14 ISO% compared to the reference TMP (Hill et al. 2010, Johansson et al. 2011). Pilot ATMP refining of *Picea glauca* resulted in energy reduction by up to 0.65 MWh/odt or 37% at tensile index 30 N.m/g and increase in pulp brightness by up to 14 ISO% compared to TMP (Gorski et al. 2011a).

Energy demand in refining of wood to pulp is governed by the critical quality variables of the paper set by the customers. In mills using mechanical pulp, these variables are typically strength (if newsprint is produced), surface roughness and air permeability (magazine paper) or bulk (book paper). In all cases, optical properties such as light scattering coefficient must also be maintained.

It has earlier been shown that fibre properties such as flexibility, surface fibrillation and the amount of split fibres are significantly improved in ATMP refining (Gorski et al. 2011a). Those properties are influenced both by the equipment configuration and the addition of process chemicals (Gorski et al. 2011b). Impact of fibre properties on paper surface properties has been studied earlier (Bradway 1956, Hoc 1989, Corson 1989, Corson et al. 2003, Aspler, Beland 1994, Forseth et al. 1997, Remé et al. 1998, Kure 1999). The conclusions are that fibre properties govern the surface properties of paper. Fibre properties such as for example the amount of split fibres (Remé et al. 1998, Kure 1999), fibre flexibility (Corson 1989), fibre wall thickness (Braaten 2000, Ferluc et al. 2010), fibre bonding (Remé et al. 1998, Skowronski 1990), collapsibility of fibres (Forseth et al. 1997, Remé et al. 1998, Kure 1999) and quality of long fibre fraction (Corson et al. 2003) influence the surface and printing properties of the final printing paper product.

Elevated rotational speed of the refiner, sometimes in combination with more aggressive segment pattern, increases the amount of split fibres in produced pulp (Kure, Dahlqvist 1998, Kure et al. 1999, 2000, Reme 2000, Johansson, Dahlqvist 2001, Sabourin 2003). This was also shown for the ATMP process both when directional feeding segments were used to elevate the intensity in the first stage refining (Gorski et al. 2011a) and when higher rotational speed of the first stage refiner combined with feeding segment pattern were used for the same purpose (Gorski et al. 2011b). Fibre flexibility, external surface development and split fibre index are typically higher for fibres produced using ATMP process compared to TMP (Gorski et al. 2011a, 2011b). It could thus be expected that such critical printing paper properties as surface roughness, air permeability and fibre roughening are improved as well when ATMP process is used compared to TMP.

Fibre roughening or surface roughening of paper is connected to de-collapse of long fibres on or near the paper surface when subjected to elevated moisture content (Hoc 1989, Mohlin 1989, Forseth et al. 1997). Stresses are induced in fibres upon their collapse during refining and papermaking. These stresses are released when fibres with sufficiently thick walls soften due to presence of moisture and the fibre collapse is thus

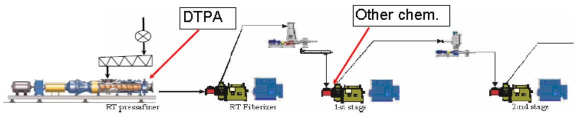

Fig 1. Pilot plant refiner configuration for ATMP (aq.) and ATMP (Mg+P) refining (when refining the TMP reference, no mechanical pre-treatment or process chemicals were used; no chemicals except DTPA were used in ATMP (aq.) refining).

reversed. This is known to be the main mechanism of surface roughening for calendered printing paper made of mechanical pulp (Forseth, Helle 1997, Norgren, Höglund 2007). Fibre swelling and debonding are also known to induce increased surface roughness (Skowronski et al. 1988, Skowronski 1990). When fibres de-collapse, the surface smoothness of paper is reduced, leading to decreased performance in coating and printing (Skowronski, Lepoutre 1985). Formation of longitudinal splits in the fibre walls was found to decrease the ability of fibres to de-collapse (Kure 1999). This was explained by weakening of the fibre wall structure by the presence of splits. Lower degree of fibre puffing was earlier observed after a heatset treatment for pulp refined using elevated intensity. This was proposed to depend on higher amount of fibres with axial splits (Sabourin 2003). Mechanical pulp fines were suggested to restrain de-collapsing fibres, preventing them from springing back upon rewetting (Moss, Retulainen 1997). Thus, it could be expected that fines with improved bonding prevent the de-collapse of long fibres and surface roughening.

In this paper, the impact of improved fibre properties on such handsheet properties as surface roughness, surface fibre roughening and air permeability was studied. It was proposed that use of fibres produced using the ATMP process, lead to smoother paper surface and improved sheet structure which is important for the printability of SC paper. In all previous publications describing the ATMP concept tensile index was used as target variable which governed the energy demand. In this study, paper properties used as quality target when manufacturing SC paper were taken into consideration. Surface fibre roughening is critical in heatset web offset (HSWO) printing and was evaluated as well.

Materials and Methods

Pilot refining

ATMP refining concept is described in earlier publications (Johansson et al. 2011, Gorski et al. 2011a, 2011b). White spruce (*Picea glauca*) from Wisconsin, USA, was used as raw material for trials in this study. Process configuration can be seen in *Fig 1*. Refining of pulp, used in this study, was described earlier (Gorski et al. 2011b). In *Table 1*, chemical recipes used in refining of the three pulp batches are given.

Physical testing

Laboratory testing of whole pulp and sheets was conducted according to TAPPI standards at the Andritz Pilot Plant laboratory, Springfield, Ohio, USA. Handsheets (approximately 60 g/m^2) were prepared according to T205 from pulp disintegrated according to the same standard method. Strength properties of the handsheets were evaluated according to T220 standard. Shive content was determined using Pulmac Fractionator with a 0.10 mm slotted screen. Pulp samples from each run were shipped from Springfield pilot plant to nsiFOCUS laboratory in Halden and kept in cold storage until testing. Laboratory sheets with recirculated white water were manufactured according to ISO 5269:2:1998.

The sheets were calendered in a laboratory calendar (Enfoplan OY EP-210) at 150 kPa nip load (3 nips on each side). Optical properties of the sheets were tested according to ISO 2470:1999 and ISO 2471:1999. PPS was measured according to SCAN P21:67 and air permeability according to SCAN P19:78. PPS was also used to evaluate surface roughening, see schematic illustration of the procedure in *Fig 2*. Water application in a printing press was used to simulate HSWO (heatset offset) printing process. PPS was measured in marked places on the sheets before the application of water. After that 0.028 g of water (comparable amount to HSWO printing) was applied to each sheet using Prufbau Offset Attachment to a Multi Purpose Printability Tester followed by a heater. PPS was then measured again in the same places on the sheets and a measure of surface roughening could be obtained by comparing PPS before and after the press nip where water was applied to the sheet surface.

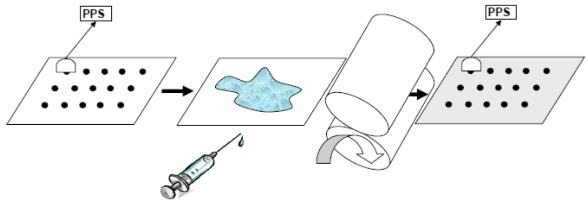

Fig 2. Laboratory setup for measurement of surface roughening of calendered laboratory sheets (measurement of initial PPS is followed by wetting, hot nip in a laboratory printing press and then measurement of final PPS).

Table 1. Pulps and chemical recipes (dosages are given on oven-dry pulp)

Pulp	Chemical recipe	Residual pH
ATMP (Mg+P)	DTPA 0.4 %, $Mg(OH)_2$ 1.4%, H_2O_2 2.6%	7.4
ATMP (aq.)	DTPA 0.4%	5.5
TMP	No chemicals	5.4

Characterization of fines and long fibre fractions

Pulp fibres, used in this study, were characterized by Paper and Fibre Research Institute (PFI) for an earlier publication (Gorski et al. 2011b). Such fibre properties as external and internal fibrillation as well as the amount of split fibre material were accessed using such techniques as settling (Wakelin 2004), FibreMaster bendability (Karlsson et al. 1999) and SEM characterisation (Reme et al. 2002).

Fines fraction was separated from pulps using a Britt Dynamic Drainage Jar (BDDJ) with 100-mesh screen according to T261 (Britt 1973) and mixed with model long fibre (separated using BDDJ from commercial SC-grade disc filter pulp, CSF ~40 ml). Laboratory sheets containing approximately 30% fines fraction and 70% model long fibre fraction were produced using recirculated white water. The properties of the sheets were measured using standard laboratory techniques already described.

Results and discussion

Surface and bulk properties of calandered sheets

Air permeability and surface roughness (measured as PPS) of paper are properties commonly used for quality control in SC paper mills. Surface roughness is a quality target crucial for SC paper used for rotogravure printing. *Figs 3* and *4* show that both characteristics were improved significantly using the ATMP (aq.) and ATMP (Mg+P) process concepts compared to TMP refining. Both air permeability and PPS depend on how well the fibres are developed. Lower air permeability and PPS of the sheets made from ATMP (aq.) and ATMP (Mg+P) confirm that higher specific surface area index and bendability of ATMP (aq.) and ATMP (Mg+P) fibres translated into improved paper properties.

The amount of axially split fibres was higher in ATMP (aq.) and ATMP (Mg+P) pulp compared to TMP (Gorski et al. 2011b). The equipment configuration was found to have major influence while the addition of process chemicals only had minor influence. Axial splits are known to reduce the elasticity and the ability of fibres to spring back to their original shape, thereby reducing surface smoothness (Kure 1999, Sabourin 2003).

An increase in the amount of split fibre material from 20% to approximately 40% was measured when rotational speed of the refiner was elevated from 1500 rpm to 2000 rpm. Amount of split fibres was also shown to increase from 40% to 50% when plate pattern was changed from “holdback” to “expel” and rotational speed was kept constant (Kure 1999). Significantly lower increase was obtained with a combination of elevated rotational speed and expelling segments in this study. This can be explained by differences in what was considered a split fibre. Ten years ago the technique did not distinguish between axial splits in the fibre walls and fibre wall pores, which it does today. Also, a different material (Norway spruce) was used which might have influenced the results since the amount of split fibres depends on the average fibre wall thickness which varies between the species.

Improvement of surface characteristics could also have been caused by reduction of fibre size (Kure 1999, Reme 2000). This is logical since smaller particles would form a denser network with smoother surface. However, the reduction of mean fibre wall thickness was approximately similar for all studied pulps (Gorski et al. 2011b). It was earlier found that ATMP (aq.) and ATMP (Mg+P) contain significantly less shives (~0.1%) compared to the TMP reference (~2 %) (Gorski et al. 2011b). There was no difference in the shives content of ATMP (aq.) and ATMP (Mg+P) whereas there was a significant difference in PPS and air permeability of sheets, made of those pulps. It seems that the improvement of such critical printing paper properties as PPS and air permeability in this study was caused by the improvement in the

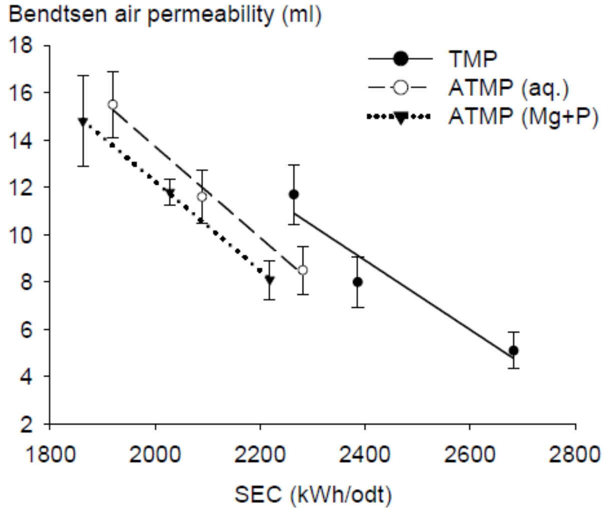

Fig 3. Air permeability of calendered laboratory sheets. Using a multivariate linear regression (R^2=0.96) it was verified that in this trial pre-treatment + intensity and specific energy demand were significant on 90% confidence level whereas the addition of chemical agents was not. Error bars for individual points denote standard deviation, obtained during laboratory testing.

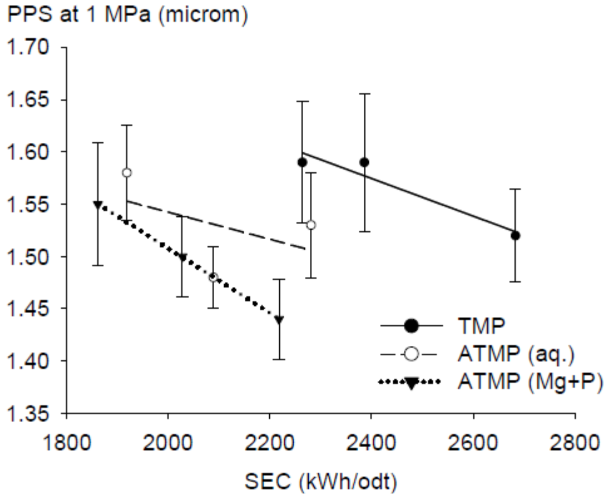

Fig 4. PPS of calendered laboratory sheets. Using a multivariate linear regression (R^2=0.72) it was verified that in this trial addition of chemical agents was significant on 90% confidence level, whereas specific energy and pre-treatment + intensity were not. Error bars for individual points denote standard deviation, obtained during laboratory testing.

development of such fibre properties as bendability, external surface area and split fibre index in ATMP refining. Both the ATMP process configuration and the addition of chemicals had a significant impact.

It was earlier shown that PPS and density, and therefore also probably air permeability, decreased with increased amount of split fibres in a pulp (Kure, Dahlqvist 1998). Increased amount of split fibres was shown to lead to improved surface properties (Braaten 1997) and decreased surface roughness (Kure 1999). Apart from the amount of split fibres, increased surface smoothness was also correlated to improved fibre bonding (Amiri et al. 1996, Hallamaa, Heikkurinen 1997, Braaten 1997, Nesbakk, Helle 2002). Improved bendability (internal fibre development) was earlier shown to decrease surface roughness (Nesbakk, Helle 2002). The bonding ability of ATMP (Mg+P) fibres was improved compared to ATMP (aq.) and TMP fibres, which was earlier shown by higher degree of internal and external development (Gorski et al. 2011a, 2011b).

ATMP process yields more flexible and better developed fibres with an increased share of split fibre material. Thus it is reasonable to expect that fibre roughening will decrease when the ATMP process is used compared to TMP. The surface roughening was significantly higher for TMP compared to ATMP (aq.) and ATMP (Mg+P), *Fig 5*. Lowest initial PPS was achieved using the ATMP (Mg+P) process and it also gave lowest final surface roughness of calendered laboratory sheets. The magnitude of roughening, however, was similar for ATMP (Mg+P) and ATMP (aq.) pulps. This is somewhat surprising considering that the ATMP (Mg+P) process yielded somewhat more split fibres compared to the ATMP (aq.) process.

If surface roughening at all energy levels is compared, it can be seen that initial and final PPS of ATMP (aq.) and ATMP (Mg+P) is similar at lower energy input but there is a significant difference at higher energy input, *Fig 6*. This correlates with the results from the fibre characterisation, where the difference in the split fibre index and surface index was larger at higher energy input levels (Gorski et al. 2011b). This could be one more indication of the impact that the reaction time of chemicals between the refining stages has on the energy efficiency in refining. In the pilot trials, described in this paper, the pulp was stored in drums between the refining stages. Residence time varied between 30 and 120 min. This effect of storage was however not evident in the development of such sheet property as tensile index, which was used for evaluation of the energy demand in refining previously (Johansson et al. 2011, Gorski et al. 2011a, 2011b).

Good correlation was found between the PPS of the calendered sheets and the split fibre index of the pulps in this study, *Fig 7*. This correlation was also reported earlier (Kure 1999). This confirms that split fibres, which were earlier proposed to collapse easier upon refining, form a smoother surface which leads to reduced PPS. However, other fibre properties such as flexibility and surface index were also found to be developed better in ATMP process compared to TMP. Thus, a firm conclusion that it is the increase in the split fibre index that caused the decrease in PPS can not be drawn. It seems more probable that it was the combination of the increased efficiency in the development of all above mentioned fibre properties that resulted in decreased surface roughness.

PPS gives a very general surface characterisation which is the weakness of the method (Forseth and Helle 1997). In the future, an attempt should be made to use other techniques (for example laser profilometry) to characterize moisture-induced surface roughness. When evaluating final papermaking properties of pulp, produced for SC paper, it is important to consider that a pulping line in an SC paper mill normally includes extensive screening and selective reject refining. The scope of this paper was

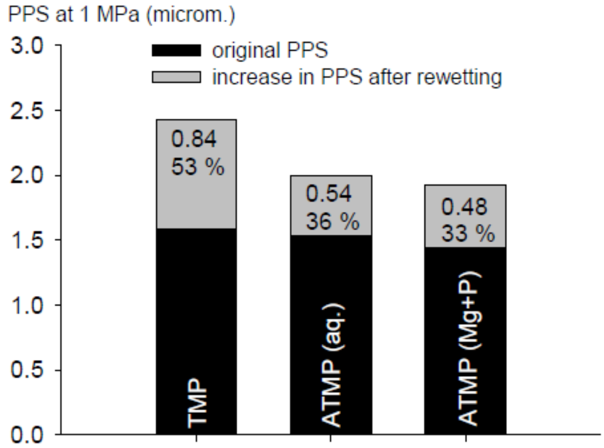

Fig 5. Surface roughening of calendered laboratory sheets. By using a multivariate linear regression (R^2=0.76) it was verified that specific energy and pre-treatment + intensity were significant on 90% confidence level, whereas addition of chemicals was not. Comparison is made at similar energy input in refining.

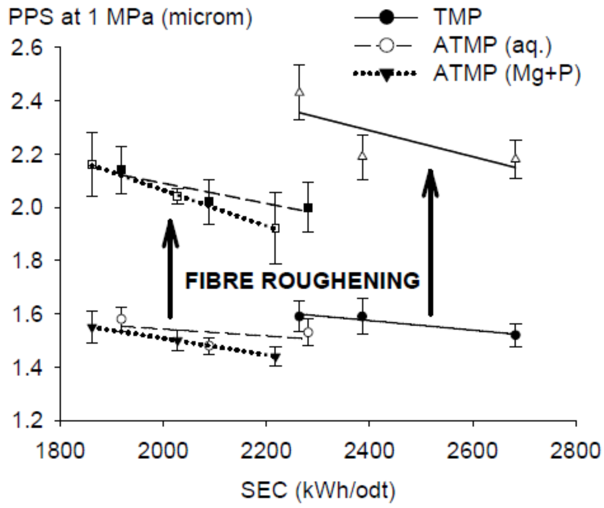

Fig 6. Surface roughening of calendered laboratory sheets made of pulps with different energy inputs.

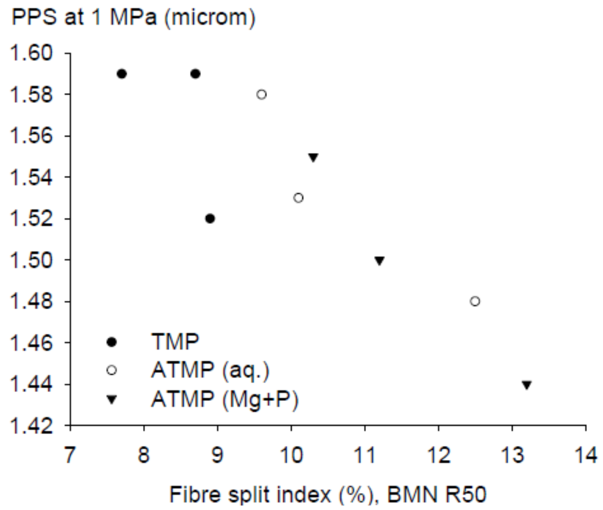

Fig 7. PPS of calendered laboratory sheets vs the fibre split index (based on earlier split index measurements, Gorski et al. 2011b).

to compare mainline pulps and thus some of the aspects, connected to reject refining, could not be covered. Selective refining of pulp, produced for SC paper is aimed at thick and coarse fibres. This is the kind of fibres which are known to increase surface roughness of paper and thus they would be treated much more in a typical SC pulping line compared to mainline pulp. Typical energy input in selective refining after fibre separation in an SC mill is 50-100 % of the mainline energy input. Due to the fact that ATMP fibres were found to be more developed at similar energy input, final quality of ATMP would probably be different when subjected to screening and selective refining. Less energy input would be needed in the mainline refining to achieve certain fibre quality and fewer fibres would need the selective treatment. The exact significance of this for the final paper quality and the energy demand in refining can be studied, if pulp screening is included in the scope of the experiments.

Influence of fines quality on calendered sheets made of model fibres

It was earlier proposed that improved bonding of long fibres due to presence of fines reduces the fibre roughening by restraining the fibres ability to de-collapse (Moss, Retulainen 1997). Thus, better bonding of the fines fraction could be proposed to decrease the magnitude of fibre roughening. This could not be confirmed in this study – the magnitude of surface roughening was not influenced by the type of fines, *Fig 8*. PPS was found to increase when ATMP (Mg+P) fines were mixed with model long fraction compared to the ATMP (aq.) fines and TMP fines. It was earlier found that tensile index increased with 3.5 N.m/g (6%) when ATMP (aq.) fines were added instead of TMP fines and another 1.5 N.m/g (10% in total) when ATMP fines were added. At the same time, the density of sheets, made with addition of ATMP (aq.) fines, was 14 kg/m^3 higher compared with sheets, made with addition of TMP fines (Gorski et al. 2011b). This was explained by improved bonding ability of the fines, which was shown to be influenced by both the ATMP process configuration and the addition of process chemicals. This increase in the bonding of the fines fraction did however not lead to decrease of the de-collapse of the fibres on the surface and surface roughening was the same for sheets, containing all three fines fractions.

Improved bonding ability of the fines in this study seemed to increase the surface roughness of the sheets. This could probably be explained by increased consolidation of the fines fraction located between the long fibres on and close to the sheet surface, see *Fig 9*. Increased consolidation of the fines fraction could have caused it to increase in density and shrink, thus decreasing the smoothness of the sheet surface.

Optical properties of laboratory sheets

Fig 10 shows the brightness of the pulps. Final brightness of the ATMP increased by 10 ISO %. The increase in brightness was due to the bleaching action of hydrogen peroxide added to the first stage refiner in ATMP (Mg+P) refining. It should be taken into account that the dosages of peroxide and alkali were not optimized for bleaching.

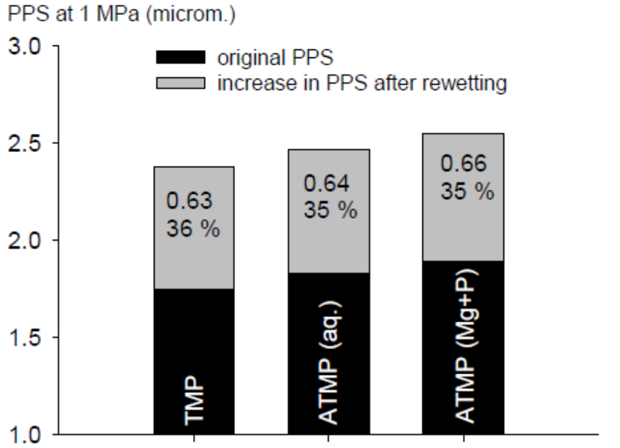

Fig 8. Surface roughening of calendered laboratory sheets made of model long fibre fraction mixed with 30 % (weight) of three different fines types. Comparison is done at similar energy input in refining.

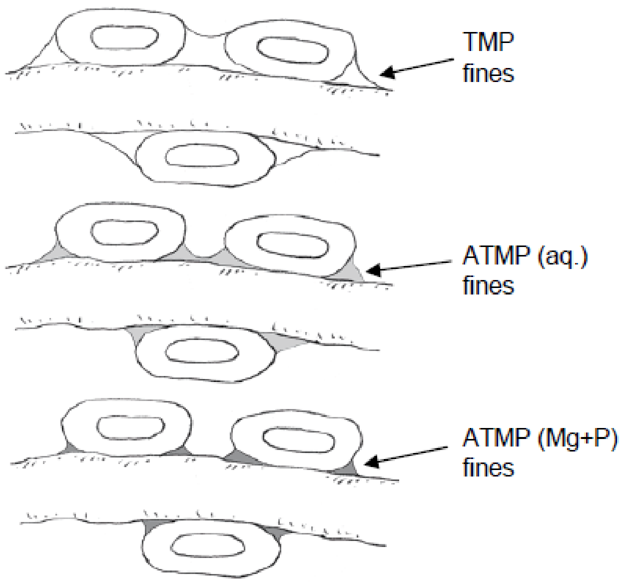

Fig 9. Influence of different types of fines on the surface roughness of paper.

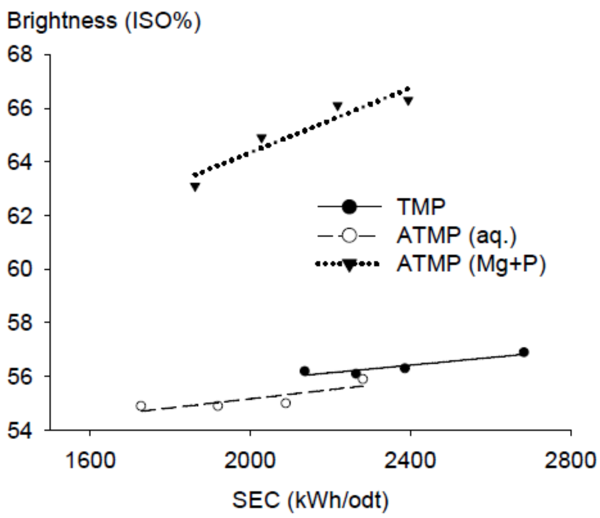

Fig 10. ISO brightness development of the pulps

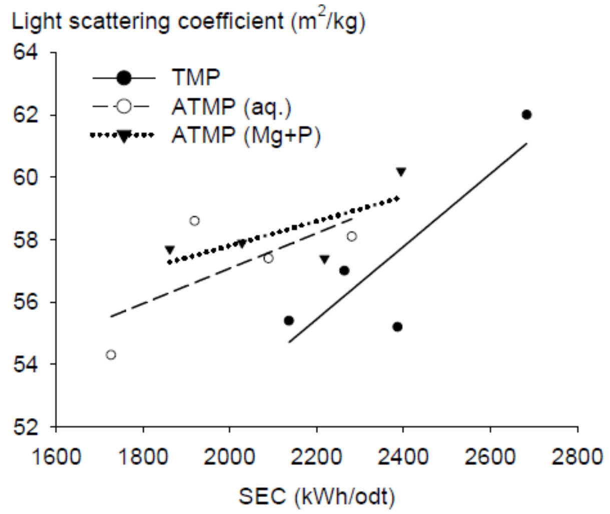

Fig 11. Light scattering coefficient of the handsheets

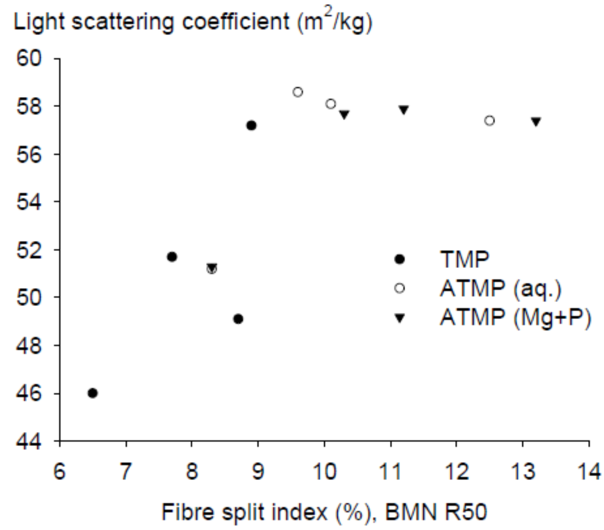

Fig 12. Light scattering coefficient of the handsheets vs fibre split index of the pulps (based on earlier split index measurements, Gorski et al. 2011b).

Higher increase in brightness (14 ISO%) could be achieved in earlier studies using the ATMP (Mg+P) concept (Johansson et al. 2011, Gorski et al. 2011a). Decreased bleaching efficiency in this study compared to earlier studies on the same raw material was proposed to be caused by hydrogen peroxide decomposition due to reasons, that could not be uncovered (Gorski et al. 2011c).

Light scattering coefficient is an important printing paper property. For the pulps, used in this study, it was earlier determined using statistical analysis that ATMP (aq.) and ATMP (Mg+P) contain the same amount of fines compared to the TMP reference at equal tensile index (Gorski et al. 2011b). Thus, compared at similar energy input, ATMP (aq.) and ATMP (Mg+P) would have higher content of fines material compared to TMP. Development of light scattering coefficient in ATMP and TMP refining can be seen in *Fig 11*. Process configuretion had significant effect on the development of the light scattering coefficient which was higher for ATMP (aq.) compared to TMP at equal energy input in refining. The light scattering of ATMP (Mg+P) was somewhat higher compared to ATMP (aq.) but the difference was smaller. This correlates with previous results indicating that in this study, the process configuration had major impact on the physical properties of handsheets while the addition of the process chemicals had a minor impact on the whole pulp handsheet properties.

It was earlier shown that increased number of split fibres resulted in increased light scattering of pulp, but the correlation was rather poor (Kure 1999). It was proposed that other factors such as increased surface fibrillation of the fibres probably increase the light scattering coefficient as well. In this study, positive correlation was found between the split fibre index and the light scattering coefficient of the sheets, *Fig 12*. However, improved surface area index witnessing about increased surface fibrillation was also measured. It is not clear which of the observed phenomena led to improved light scattering for ATMP. It was most probably caused by a combination of both.

Conclusions

- Both the process configuration and the addition of process chemicals had significant impacts on PPS, air permeability and surface fibre roughening of calendered laboratory sheets. Equipment configuration of the ATMP process was found to have a major influence while the addition of process chemicals had a minor influence in this study. The improvement of paper properties could be connected to the improvement in the development of fibre properties in refining, measured earlier.
- Laboratory sheets made of ATMP (Mg+P) had lowest surface roughness after rewetting due to lowest initial surface roughness. The magnitude of roughening was however similar for ATMP (Mg+P) and ATMP (aq.) and significantly decreased compared to the TMP reference.
- Model long fibre sheets with ATMP (Mg+P) fines had highest surface roughness of all three studied fines types. Model long fibre sheets with TMP fines had lowest surface roughness. This was probably caused by increased consolidation of the fines fraction with improved bonding ability, leading to rougher surface structure of model long fibre sheets. The added type of fines did not have any significant effect on the magnitude of the surface roughening.

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