

Compression refining: the future of refining? Application to Nordic bleached softwood kraft pulp

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ABSTRACT: A new compression refining technology based on the kneading of high consistency pulp has been selected and tested in various conditions with a model Nordic bleached softwood kraft (NBSK) pulp. The method uses a kneader mixer referred to as the ultra continuous mixer (UCM) to condition the pulp. Its performance levels were also compared with those obtained with traditional low consistency (LC) refining of the same pulp.

Compression refining of the NBSK pulp with the UCM led to a much better °SR/strength compromise than conventional LC refining. High strength properties can also be achieved by compression refining, in a range similar to/or better than LC refining. The higher the strength required, the greater the advantages of this technology: for a given strength, a difference of up to 10°SR can be obtained as compared to LC refined pulp. Moreover, a higher tear index can be obtained with compression refining, since fiber cutting is greatly reduced.

The lower °SR is due to the release of fewer cellulosic fines, which also results in the manufacturing of new papers combining a high strength and a high permeability that cannot be obtained with traditional LC refining. Indeed, with LC refining, a high strength is generally associated with a low permeability. Upscaling this technology seems to be possible since large production devices are already on the market for applications other than paper/pulp. With this new pulp behavior, papermakers will have to learn to think differently, as paper strength and °SR can now be decorrelated.

Application: A new refining technology is proposed: compression refining allowing development of strength properties while keeping good pulp drainability. Strength and drainage are therefore decorrelated. This technology will allow a reduction in carbon dioxide emissions associated with the papermaking process.

Today, every mill in the world includes at least one conventional refining stage carried out at low consistency (4%–5%) using disk or conical refiners. Around 300 refiners have been installed in France (for around a hundred mills), and 15,000 worldwide. Paper mills therefore have an average of three refiners in which to prepare pulp. Between 50 and 400 kWh/ton are applied to the pulp to obtain the desired fiber flexibility properties, enabling the mechanical properties of the papers made from these fibers to be adjusted. Conventional refining is systematically associated with a deterioration in drainage (i.e., an increase in °SR), so much so that an increase in mechanical properties is systematically associated with an increase in °SR for papermakers.

The compression refining process has yet to be developed at an industrial scale. The first research work was carried out in the 1960s by Murphy [1]. Murphy used a conventional laboratory PFI refiner, which involves refining a pulp fed between two concentric crenelated rolls, with the inner roll in planetary motion. Murphy varied the speed differential of the concentric cylinders to vary the tradeoff between shear forces and compression forces, and showed that mechanical properties were developed without altering drainage under conditions of pure compression (zero

speed differential in the gap between the cylinders).

In addition to the impact of the speed differential, Murphy also showed that: 1) the most appropriate pulp concentration for treatment was 10%–15%; 2) increasing the compression intensity accelerated refining; and 3) reducing the gap increased the compression intensity to a threshold value.

Since Murphy's seminal work, various other authors have studied this concept. Hartman [2] designed a device enabling wet handsheets (manufactured on a dynamic handsheet former) to be compressed several times. These successive compressions significantly increased mechanical properties, again without altering dewatering. The University of Wageningen [3,4] developed a laboratory device and then a small pilot machine to also deliver only compression forces. They showed that with this pilot machine they could develop mechanical properties without altering dewatering, and that refining energy was reduced by 27% at a given mechanical property. Kerekes [5], Kerekes and Senger [6], and Goosen et al. [7] studied the effect of multiple compressions on a fibrous mat and showed that, for compression forces to increase mechanical properties, the fibrous mat had to be destructured between each compression so that compression forces were applied to a multitude of fibers.

They also quantified the intensity of the compression forces to between 0.25 and 2.5 kJ/kg/impact. This compares with 11 to 16 kJ/kg/impact in the case of conventional refining. It was concluded that, to be effective, this type of compression refining must deliver multiple, low-intensity compressions. Finally, Eibinger et al. [8] also studied compression refining with a PFI laboratory refiner in compression mode (zero speed differential) with a smooth-walled inner rotor to further reduce shear. Their study confirmed the previous results (improved mechanical properties and better drainability).

In summation, the literature clearly shows the benefits of compression refining, but to date no industrial device based on this concept has been developed. While the principle of the PFI laboratory device is entirely appropriate, it has not been possible to develop an industrial device enabling continuous refining. The Centre Technique du Papier (CTP) in Grenoble, France, began working on this topic in 2018, in collaboration with French and foreign paper manufacturers, with the aim of selecting and testing various alternative refining technologies that enhance compression forces.

One alternative refining technology has been selected, tested, and compared with the conventional LC refining. This technology was selected to deliver mainly compression forces with minimal shearing forces, which are assumed to create too many small fines elements, reducing drainage on the paper machine. Compression forces are necessary to develop fiber flexibility in order to increase the bonding surface between fibers, and therefore, the strength properties.

The alternative compression refining technology uses a commercially available mixer, the ultra continuous mixer (UCM), that is not currently in use in the paper industry but is already widely used in several areas of other industries. Applications include technical ceramics (catalyst supports and batteries), single screw extruder upstream mixing, an-

imal nutrition (coating of active ingredients with fats), and emulsions. This device works continuously in a wide viscosity range (50,000 to 10,000,000 mPa·s), from mixing liquids to processing viscous pastes such as technical ceramics. The UCM is composed of co-rotating shafts on which various blades are mounted. It delivers combined compression and shear forces, but the level of shear is very low since the two co-rotating shafts in the mixer have a rather small diameter and a low rotating speed (from 50 to 350 rpm), delivering a speed at the periphery of the blades close to the chamber wall between 0.1 and 0.5 m/s that is much lower than that observed in an LC refiner (between 25 and 30 m/s). For the different profiles tested (hereafter referenced as “standard or medium shear” and “high shear”), the UCM shear is not at all comparable with the shear delivered in an LC refiner. The mechanical action delivered to fibers is based much more on compression forces than on shearing forces.

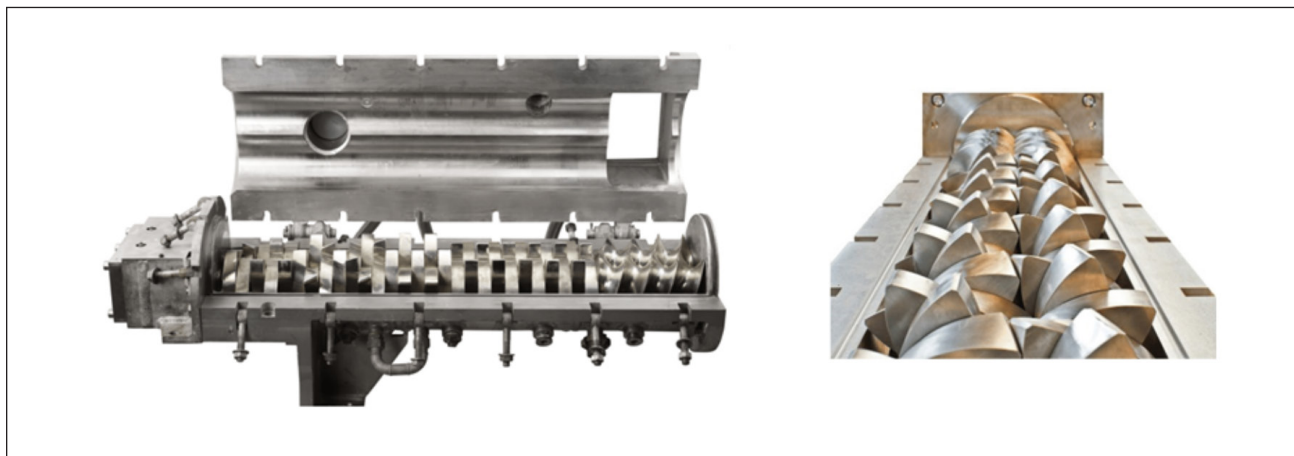
MATERIALS AND METHODS

Description of ultra continuous mixer

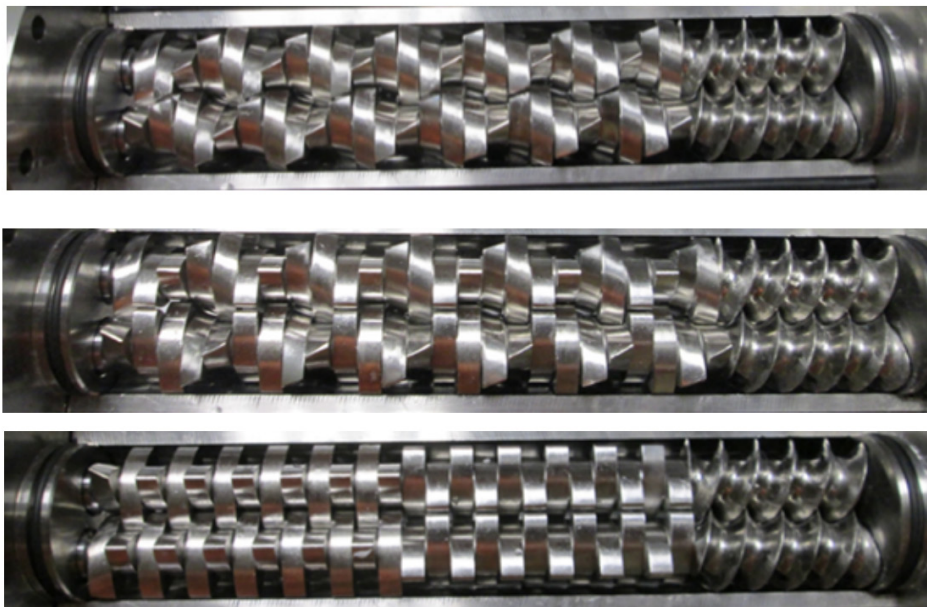
The laboratory UCM used in this study is described in **Figs. 1–3**. The diameter of the blades for this lab equipment is 25 mm, and the gap between facing blades and between the blades and the chamber wall is 300 µm, similar to that observed between plates in an LC refiner. To supply the device, the dry pulp is first repulped in a Lhomargy-type laboratory pulper at 5%. It is then thickened in a Büchner funnel or centrifuged before being fluffed. This obtains a concentrated pulp (30% to 40%) that is then fed continuously into the UCM with an extraction screw from a small tank. The pulp is then diluted inline at the UCM inlet before being treated in various conditions.

Description of pulp studied

The new UCM technology was tested with a Nordic bleached softwood kraft pulp (NBSK) pulp from Stora Enso



1. Description of the ultra continuous mixer (UCM), showing a view of the whole device (left) and closeup of some of the blades (right). Pulp is introduced from the top (right), dropping into the mixing/compression zones between the facing blades and between the blades and the chamber wall.



2. Design of the blade profiles mounted on the shaft of the UCM for Nordic bleached softwood kraft (NBSK) pulp, showing (from top to bottom) low shear, medium or standard shear, and high shear. Pulp circulation is from right to left. The pulp is introduced from the top right and removed from the bottom left.



3. Experimental conditions with the UCM mixer.

known as Supreme. This pulp has the following properties:

- Length weighted length of 1.95 mm
- Width of 29 μm measured with MorFi fiber analyzer (Techpap; Grenoble, France)
- 14°SR, measured according to ISO 5267/1 “Pulps — Determination of drainability — Part 1: Schopper-Riegler method”
- Water retention value (WRV) of 0.93 g water/g pulp, measured according to TAPPI Useful Method 256 “Water retention value (WRV)”

Initial study objectives

With the UCM, the first objectives were to study the effects of the mixing consistency, the rotating speed, the profile of the blades mounted on the two shafts, and finally, the residence time.

Conditions for mixing consistency, rotating speed, and blade profiles

When studying the effects of mixing consistency, rotating speed, and blade profiles with the NBSK pulp, the conditions were as follows:

- Mixing consistency was varied from 8% to 15% and 35% with the same production of wet pulp (pulp + water) at 1.3 kg/h, corresponding to a dry production of 104, 195, and 410 g/h, respectively. Since the internal volume of the mixer is 0.1 L, the residence time was 4.6 min for each trial.
- The rotating speeds of the blades were 50 rpm (or 100 rpm when 50 rpm was not possible) and 350 rpm.

- The profiles of the blades on the shafts for NBSK were one of these settings:
 - Low shear profile (only helicoidal blades mounted at 45°)
 - High shear (all flat blades mounted at 90°)
 - Medium/standard shear (alternating between helicoidal and flat blades mounted at 45°)

Conditions for residence time

In a second step, to better understand the effect of the mixing time, the residence time in the mixer was investigated:

- Effect of residence time:
 - 10% consistency with residence time increased by 1.7, 5, 10, and 20 min corresponding to dry pulp production of 360 to 30 g/h, respectively.
 - Rotating speed of 350 rpm
 - The profile of the blades on the shafts for NBSK was selected after preliminary trials, and the best results were obtained with alternating helicoidal and flat blades mounted at 45°, corresponding to standard/medium shear configuration.

Comparison of UCM to tradition LC disk refining

To obtain a comparison of UCM with traditional LC disk refining, the same NBSK pulp was also refined conventionally at different energy settings on CTP’s 12-in. Sprout refining plant using the following conditions:

- Energy applied: 0, 100, 200, 400, or 800 kWh/ton
- Specific edge load: 1.3 SEL (W•s/m)
- Cutting length: 10 km/s
- Rotating speed: 1500 rpm
- 60 kWh/ ton per pass

Several checks were performed on the pulps: °SR, WRV, and fiber morphological properties with the MorFi equipment (from Techpap), as previously described.

Production of handsheets

Lastly, all the refined pulps were used to manufacture 75 g/m² handsheets with the dynamic sheet former (Techpap). Wet sheets were sandwiched between 2 blotting papers, pressed (one pass with a 3.9 kg manual roll + 1 passage in a laboratory roll press under 2.5 bars), and then dried without shrinkage on a drying cylinder at 95°C for 5 min. Several sheet properties were measured in the machine direction (MD) and cross direction (CD), as described in **Table I**.

RESULTS

Effect of mixing consistency, rotating speed, and profile of the blades

The first set of experiments are reported in **Fig. 4**. The objective of this part was to optimize the conditions in order to select the best conditions for the UCM.

Effect of mixing conditions on pulp properties

The curves in Fig. 4 illustrate the combined effect of mixing consistency, rotating speeds of the mixer shaft, and various blade profiles.

When treating NBSK pulp in the mixer, a clear WRV increase is observed, especially with the blade design delivering the highest shear at all consistencies. Although there is a huge increase in °SR with the high shear profile whatever the rotating speed, the corresponding increase in °SR is not observed with the low and standard shear profile, despite an interesting increase in WRV.

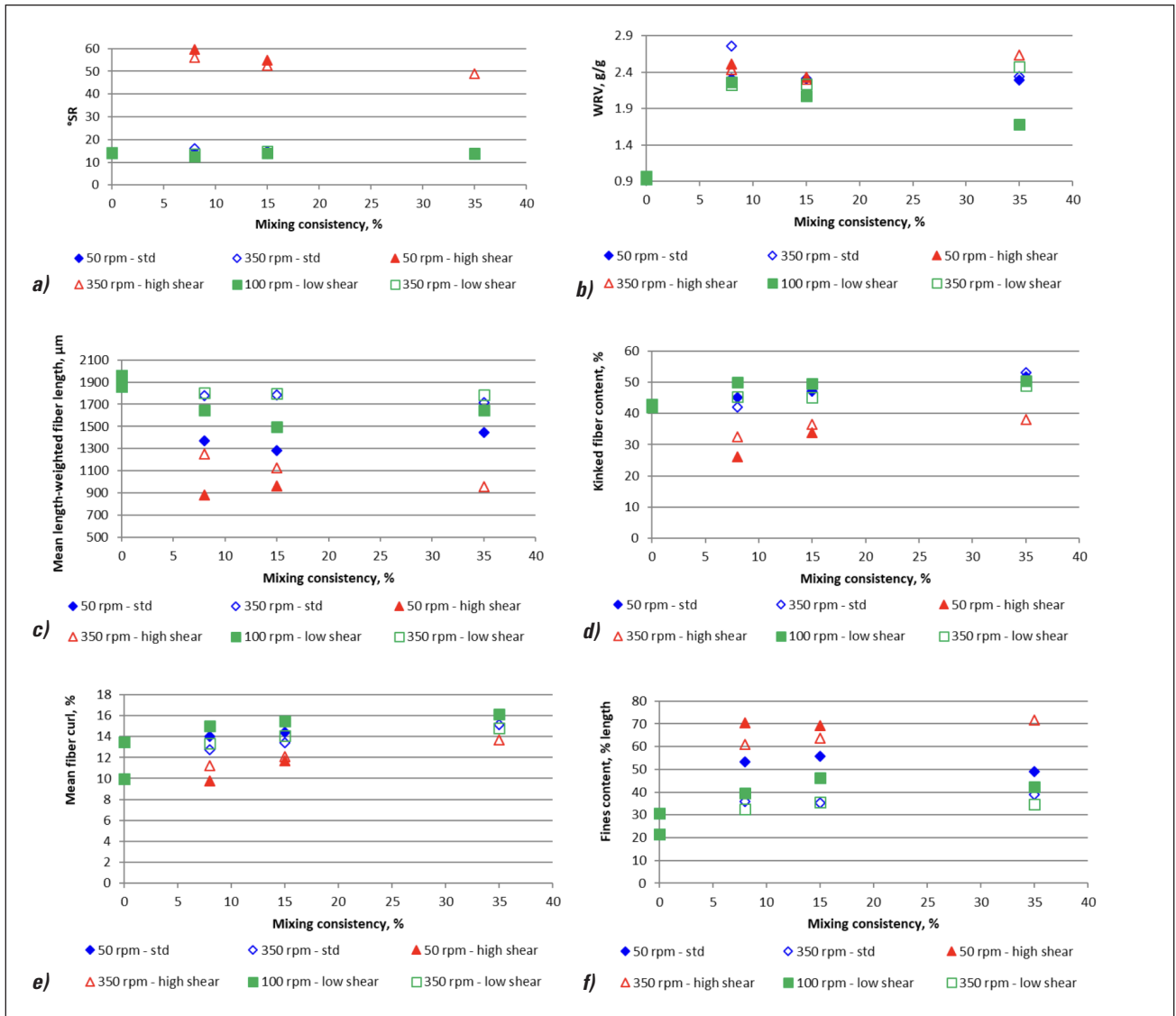
The smallest WRV and °SR increases were obtained with the low shear and standard shear blade profile.

The UCM can induce small or large variations in NBSK fiber length: from 1850 µm after thickening/fluffing, very slight fiber cutting occurs in some conditions, especially with a high rotating speed and low and standard shear (around 1800 µm), while in others, with high fiber squeezing at 50 rpm, significant fiber cutting occurs (down to

Sheet Property	Test Method	Test Description
Grammage	NF EN ISO 536	“Paper and board — Determination of grammage”
Thickness	NF EN ISO 534	“Paper and board — Determination of thickness, density and specific volume”
Tensile strength	NF EN ISO 1924-2	“Paper and board — Determination of tensile properties — Part 2: Constant rate of elongation method (20 mm/min)”
Burst strength	NF EN ISO 2758	“Paper — Determination of bursting strength”
Tear strength	ISO 1974	“Paper — Determination of tearing resistance — Elmendorf method”
Scott bond	TAPPI T 569	“Internal bond strength (Scott type)”
Permeability*	NF ISO 5636-3	“Paper and board — Determination of air permeance (medium range) — Part 5: Gurley method”

*The reported values are geometrical means of MD/CD or top/bottom.

I. Handsheet properties measured and test methods used.



4. Effects of mixing consistency (8%–15% and 35%), rotating speed (50 rpm or 100 rpm, and 350 rpm), and blade profiles (low, standard, and high shear) in the UCM on NBSK pulp's °SR, water retention value (WRV), fiber length, kinked and curled fibers, and fines generation (% in length).

880–900 μm). Significant cutting can also be obtained, especially at a high consistency.

Another effect of refining is fiber stretching and straightening due to swelling, but also due to the tension in the refiner gap. In particular, this effect is followed by a variation in kinked fibers and to a lesser extent, by curl, bearing in mind that the latter also indicates a change in fiber flexibility.

After a slight increase due to thickening/fluffing (10%–14%), the UCM leads to a slight decrease in curl with the NBSK pulp (to just 10%) at 8% pulp consistency with a high shear profile and low rotating speed. As consistency increases, the proportion of kinked and curled fibers also increases; this is particularly pronounced at 35% consistency.

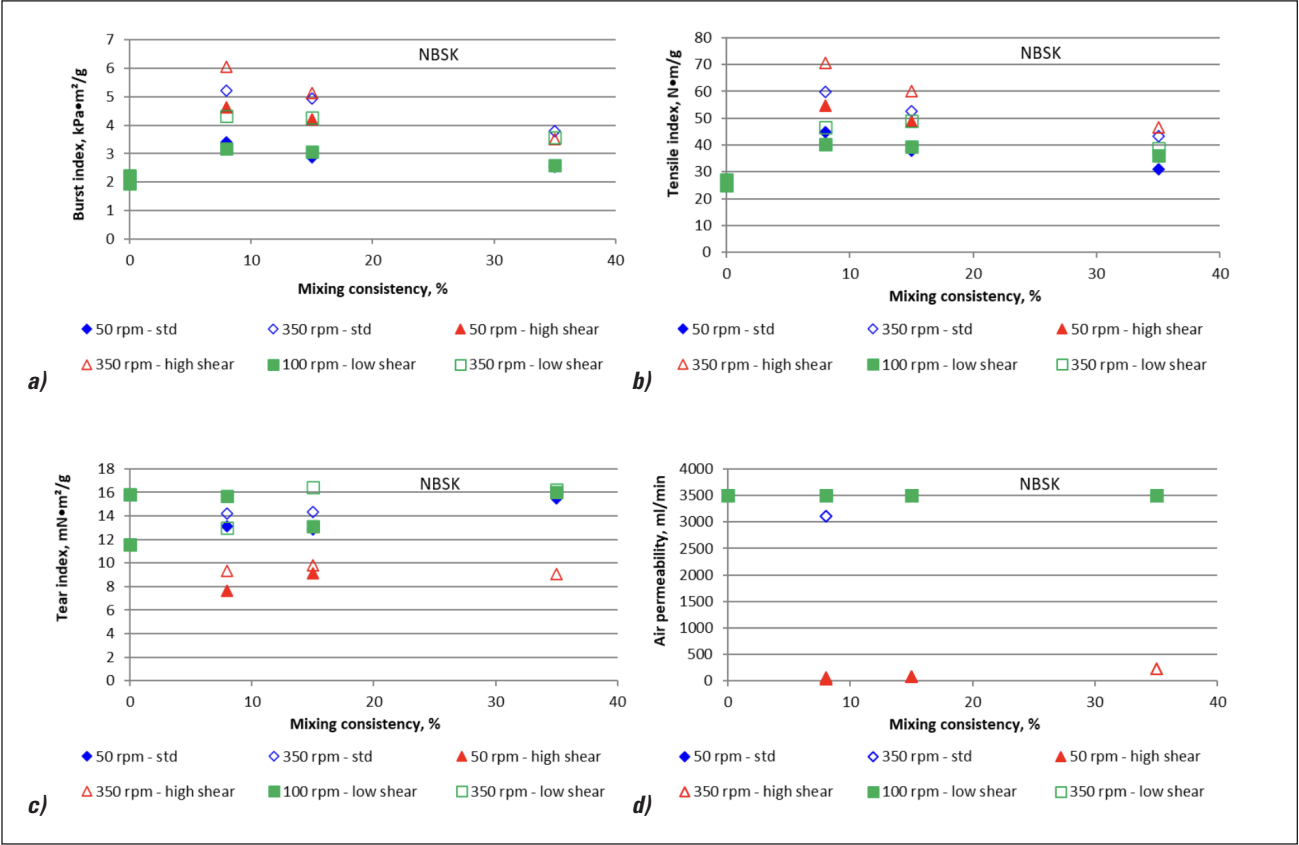
As expected due to the fiber length, in conditions with a high shear profile and a low rotating speed, we observed

a substantial release of fines elements. In smoother conditions (low shear and standard shear at 350 rpm), this release is much less pronounced.

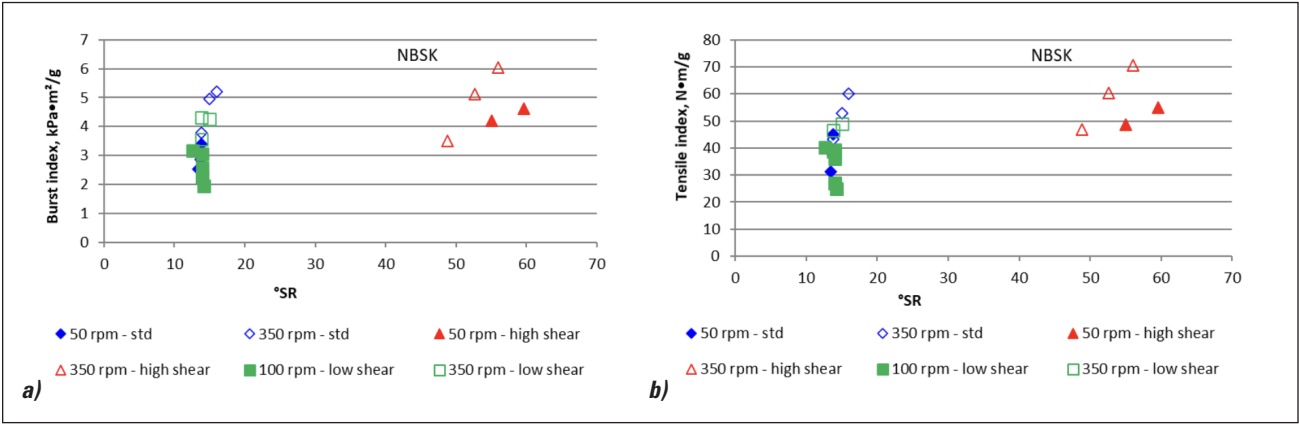
Effect of UCM mixing conditions on strength properties

The strength properties corresponding to the different mixing conditions are reported in **Fig. 5**.

Overall, large increases in strength are observed with UCM mixing. Wide variations in burst and tensile resistance are seen first, and their extent depends on blade profile, rotating speed, and consistency. The best results are clearly obtained at 8% consistency with the high shear and standard shear profiles turning at 350 rpm. The smallest increase is obtained with the low shear profile at low rotating speed.



5. Effects of mixing consistency (8%–15% and 35%), rotating speed (50 rpm or 100 rpm, and 350 rpm), and blade profiles (low, standard, and high shear) in the UCM on NBSK pulp’s strength properties, including burst index, tensile index, tear index, and air permeability.



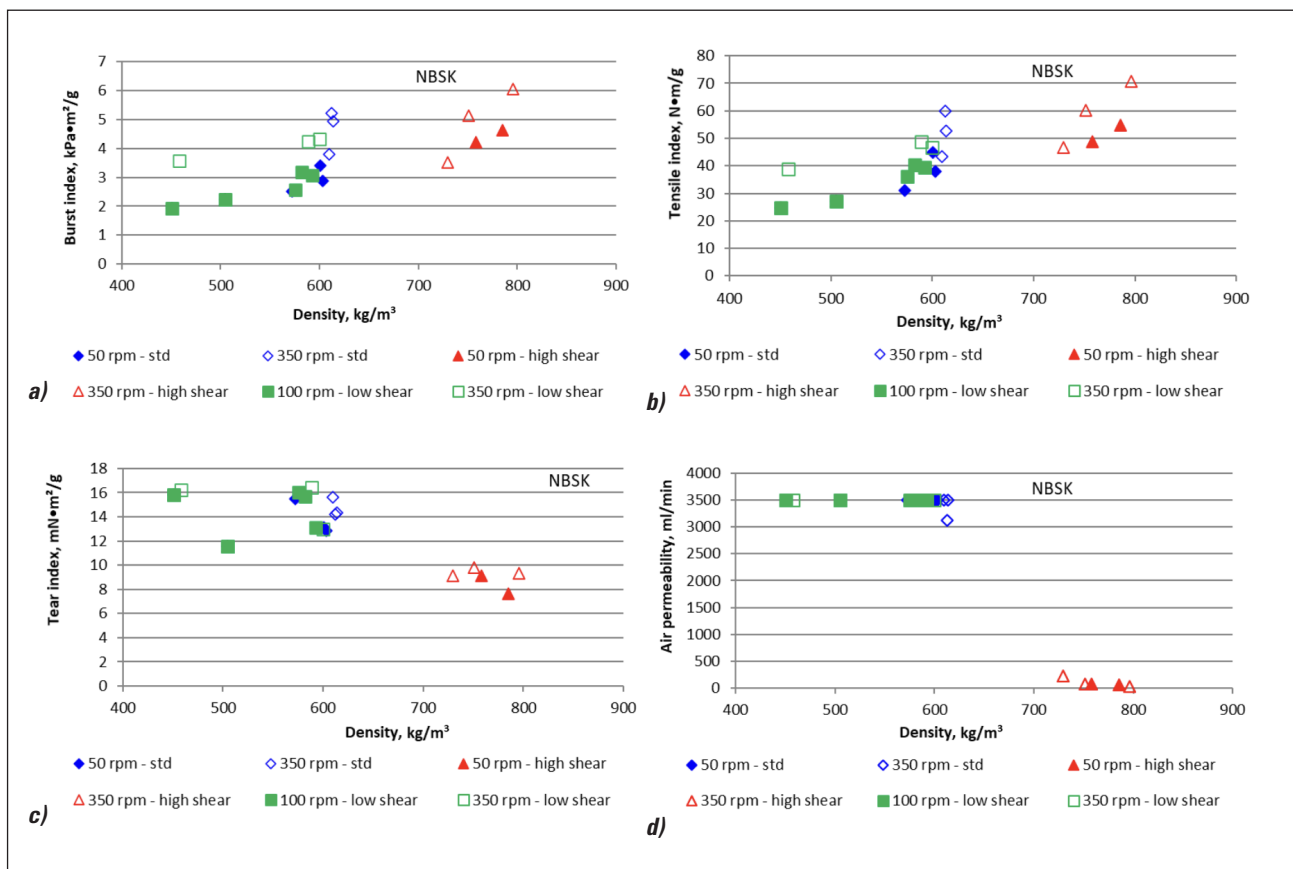
6. Effects of mixing consistency (8%–15% and 35%), rotating speed (50 rpm or 100 rpm, and 350 rpm), and blade profiles (low, standard, and high shear) in the UCM on NBSK pulp’s compromise strength/°SR for burst index, tensile index, tear index, and air permeability.

On the other hand, as far as tear index is concerned, the best results are obtained with the low shear and then the standard shear profile, while mixing concentration has a lower impact. As regards air permeability, all conditions with the low and standard shear profile lead to an open sheet, whereas with the high shear profile, the sheet is almost totally closed, whatever the mixing consistency and rotating speed.

Overall, for all of the properties, the best burst/tensile and tear index compromise is obtained with the standard shear profile and high rotating speed (350 rpm) at 8% consistency. On the whole, the low rotating speed is not recommended.

The compromise with dewatering ability is reported in **Fig. 6**.

Considering the burst/tensile index compromise, for a



7. Effects of mixing consistency (8%–15% and 35%), rotating speed (50 rpm or 100 rpm, and 350 rpm), and blade profiles (low, standard, and high shear) in the UCM on NBSK pulp's compromise strength/density for burst index, tensile index, tear index, and air permeability.

rather limited °SR increase, the best conditions are clearly obtained with the standard shear profile at 350 rpm. These results are also confirmed by the strength/sheet density compromise (Fig. 7).

Effect of UCM mixing residence time on pulp and paper properties

The effect of the pulp residence time in the UCM on the pulp/paper properties is of prime importance, as it will define the volume of the compression refiner, the production capacity, and the energy consumed.

Figure 8 illustrates the combined effect of residence time and blade profile for NBSK pulp mixing in selected conditions (350 rpm, 8% consistency, medium or high shear profile).

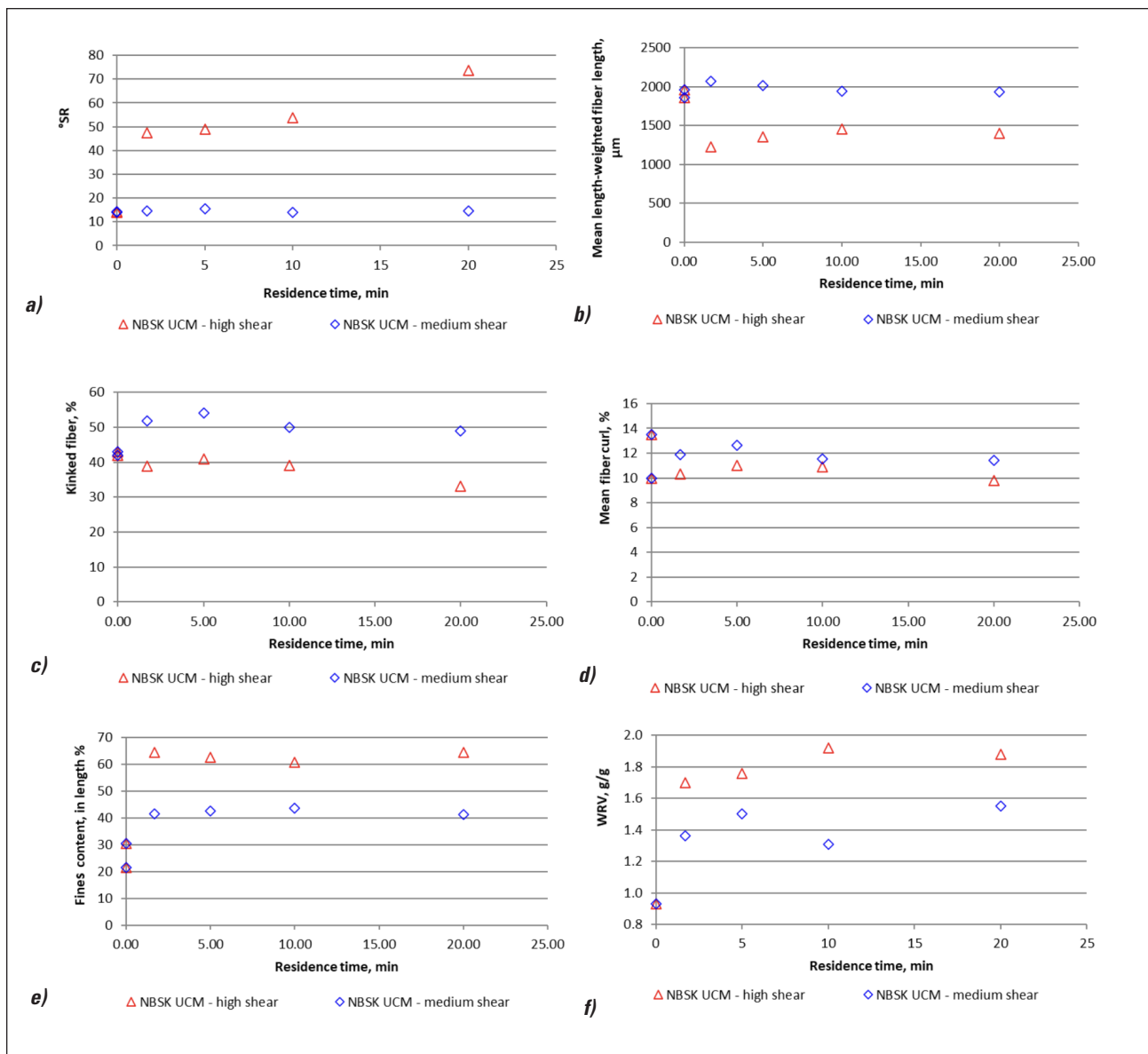
As far as fiber characteristics are concerned, no fiber cutting vs. mixing time is observed for the medium (standard) shear profile, although a slight increase in kinked fibers is observed along with a more significant increase in fines, despite the lack of °SR increase.

With a high shear profile, the results are very different: fibers are cut very rapidly (from 1960 down to 1250 µm) in conjunction with a rapid, large increase in °SR (13 to 49 after 1.7 min, and then to 72°SR after 20 min); a very

large increase in fines content (30% to 65% in present fines length); and fast fiber hydration, with WRV close to 1.9 g/g.

As far as paper strength properties are concerned, **Fig. 9** shows that mixing time has a different effect on their development; they are on the whole reached after 1.7 to 5 min. This is the case with tear index (14 mN·m²/g) and also with tensile strength (25–30 to 60–70 N·m/g). The burst index increases at first strongly and then more regularly over time, from 2 to 5.5–6 kPa·m²/g, which is also rather high. All these strength increases are obtained while maintaining a fairly permeable sheet for the standard shear profile or a closed sheet for the high shear profile.

This set of experiments already provides a basis for defining a number of recommendations for performing compression refining of NBSK in the UCM, namely: 1) run at low consistency (8 to 10%); 2) use a standard shear blade profile; 3) set a high rotating speed (350 rpm); and 4) define a residence time of 1 to 5 min. In these conditions (standard shear profile, 350 rpm at 8% consistency), the results show that fairly high strength properties are obtained with the UCM, delivering efficient compression forces in the gap between the facing blades and between the blades and the mixer chamber wall.



8. Effects of mixing times at 1.7, 5, 10, and 20 min in the UCM at 10% pulp consistency on NBSK pulp's (medium and high shear) °SR, fiber length, kinked and curled fibers, fines generation (% in length), and WRV.

Comparison of UCM mixing with a low-consistency disc refiner: strength properties vs. sheet density

All the data corresponding to the effects of the residence time in the UCM compared with LC refining are reported in **Table II**.

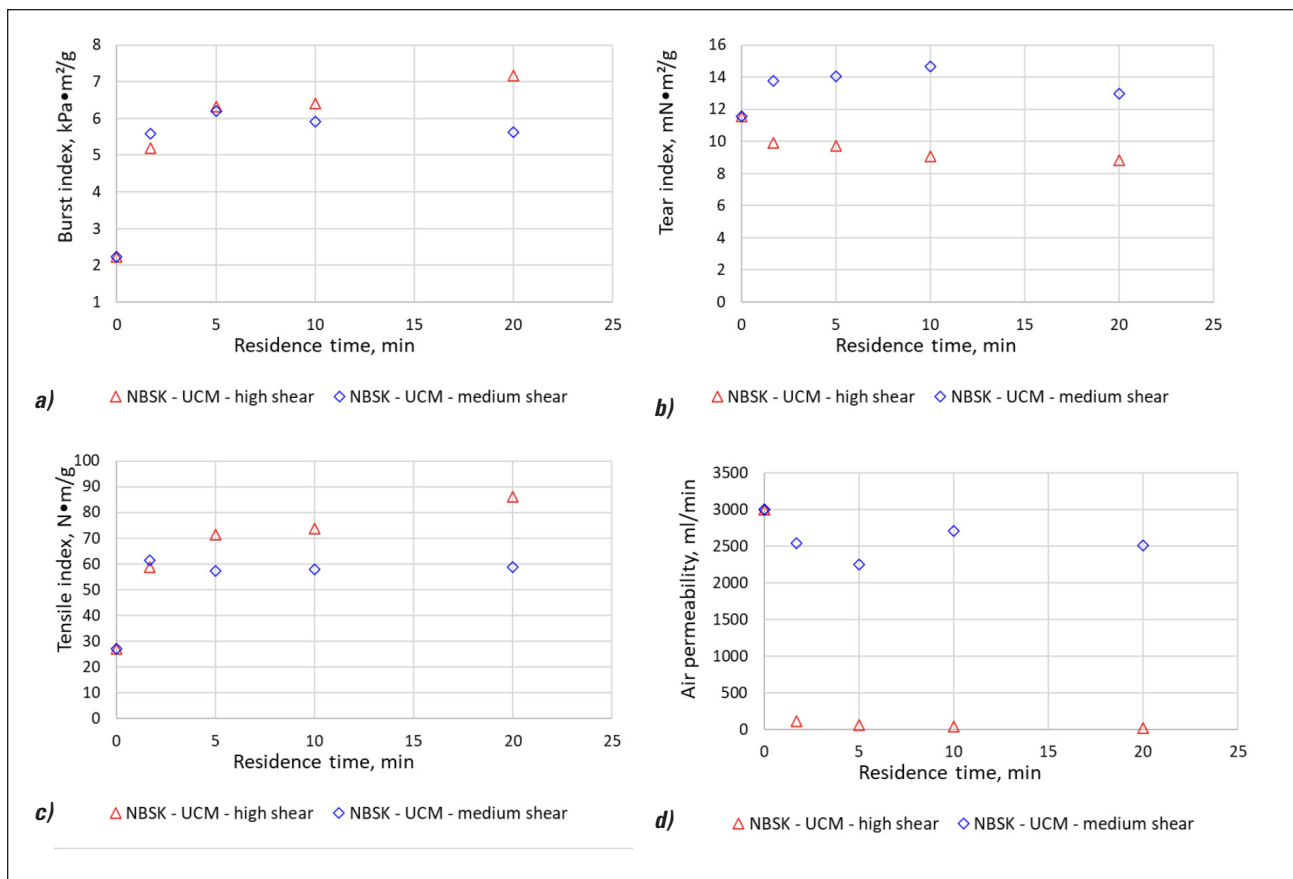
In addition, **Fig. 10** reports the variation in paper properties for conventional LC refining and compares it with UCM refining. First, it shows that the strengths obtained with compression refining (UCM mixing) of NBSK are roughly as high as those obtained with LC refining. As regards density, the values obtained with UCM mixing are generally similar for burst (around 6–6.5 kPa•m²/g for 640 kg/m³) and tensile index (around 60 N•m/g for the

same density), and tear values are overall slightly higher (15 vs. 12 mN•m²/g at 650 kg/m³). Lastly, air permeability is much higher at a given density, mainly because fewer, larger fines are released with compression refining than with LC refining. The difference is significant; for example, at 650 kg/m³, permeability is around 2500 mL/min as opposed to 500 mL/min with LC refining.

Drainage vs. strength properties

One of the main advantages of compression refining is a smaller release of small fines elements associated with a lower °SR. It was hence interesting to plot the °SR vs. strength properties compromise, as reported in **Fig. 11**.

The advantages of compression refining with UCM mix-



9. Effects of mixing times at 1.7, 5, 10, and 20 min in the UCM at 10% pulp consistency on NBSK pulp's (standard or medium and high shear) strength properties, including burst index, tensile index, tear index, and air permeability.

ing over LC refining are clearly demonstrated; the values obtained with UCM mixing for a given °SR are higher than those obtained with LC refining.

- Burst is obtained at a lower °SR (around 6.2 $\text{kPa}\cdot\text{m}^2/\text{g}$ for 15°SR for UCM mixing instead of 28°SR for LC refining) and tensile index (61 $\text{N}\cdot\text{m}/\text{g}$ is obtained for 14°SR with UCM mixing instead of 31°SR for LC refining).
- Tear values in particular are better (15.5 instead of 13 $\text{mN}\cdot\text{m}^2/\text{g}$) with UCM mixing, while keeping a low °SR.
- Lastly, air permeability is higher overall with UCM mixing, but follows the same curve as LC refining.

DISCUSSION

The effect of blade design during mixing has the greatest influence on the development of fiber properties. The high shear profile has the strongest influence on both fiber modification and paper properties, although the effect is too drastic on NBSK fibers: high tensile and burst indices; extensive fiber cutting associated with a huge reduction in tear resistance; a strong increase in °SR; and a closed sheet. Standard or medium shear is therefore recommended to obtain a better compromise. Two situations must hence be considered: a low or high rotation speed, which defines the characteristics of the compression forces. A low rotation

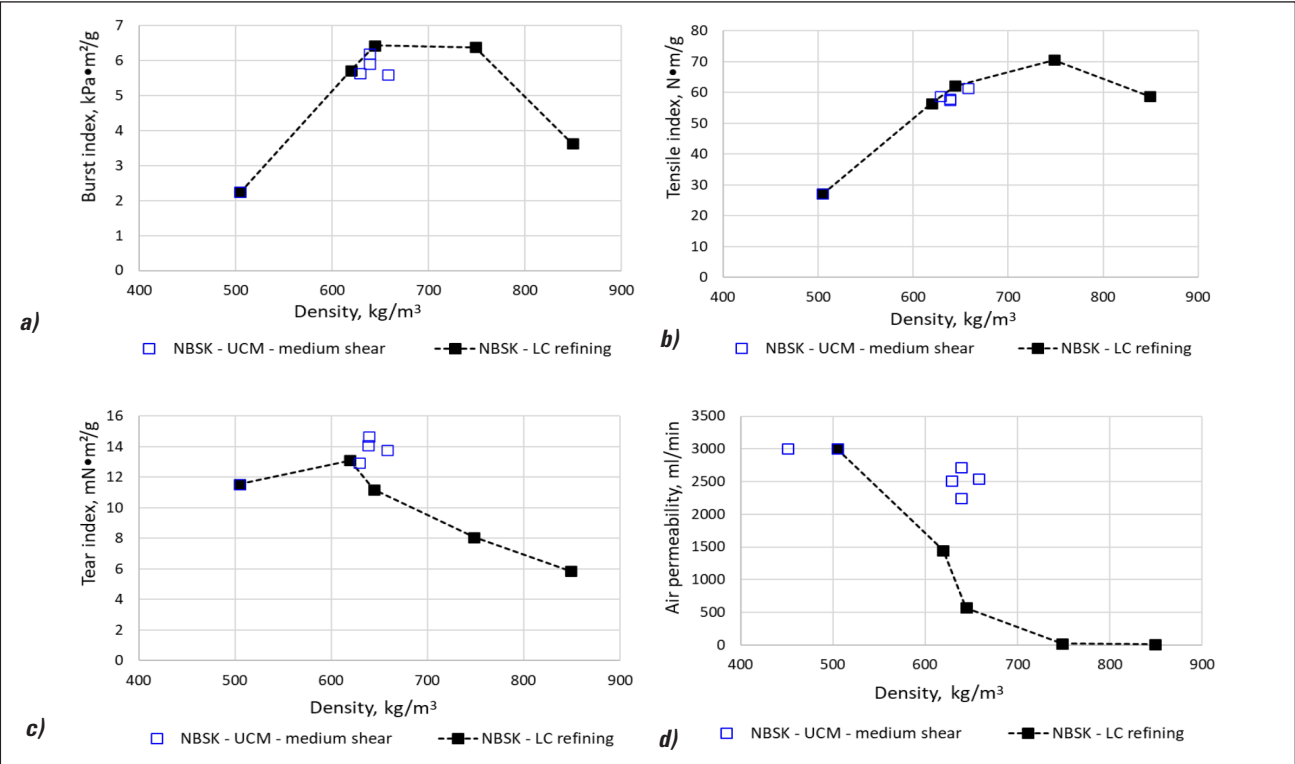
speed favors intense effects and longer compression forces despite a lower number of compressions, whereas a high rotation speed increases the number of compressions, but makes them shorter and less intense. Therefore, contrary to what may be expected, a low rotation speed is less suitable, as it increases the fiber floc squeezing intensity in the gap of the device. It reduces the fiber length, resulting in lower development of paper strength, whereas the °SR achieved is rather high. On the other hand, at a high rotation speed, fiber floc squeezing is less intense, which limits the impact on the fiber morphology and maximizes the benefit of the compression forces on the paper strength while altering the pulp drainability, to a lesser extent.

In other words, these conditions allow the best compromise between paper strength development and pulp drainability to be reached. It is also shown to be far better than that obtained with conventional LC refining. This better drainability results from the release of fewer, larger fines elements during UCM mixing and is consistent with the lower °SR. Despite this lack of fines elements, low permeability can be achieved, thanks to the higher fiber flexibility and/or collapsibility. More generally speaking, at a given density, the sheet obtained is more open, enabling the development of new papers with high strength and high per-

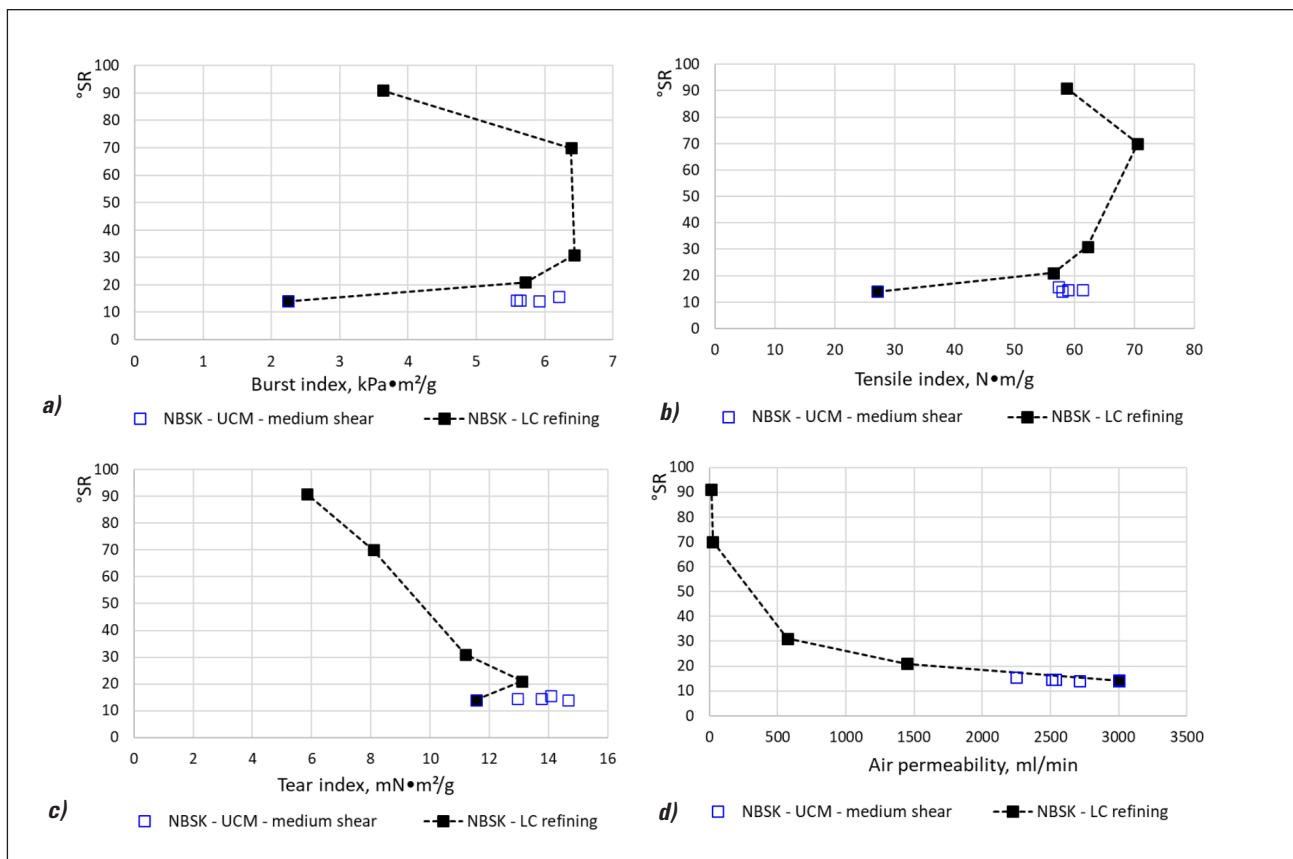
	Residence Time, min (for UCM) or energy, kWh/ton (for LC refining)	°SR	WRV, g/g	Density, kg/cm³	Burst Index, kPa•m²/g	Stretch, %	Elasticity Modulus, MPa	Tensile Index, N•m/g	TEA, J/m²	Tear Index, mN•m²/g	Air Permeability, mL/min
NBSK – UCM medium shear	0	14	0.93	505	2.24	2.68	1278	27.1	43.9	11.55	3000
	2	14.5	1.36	658	5.59	6.27	2163	61.4	213.9	13.76	539
	5	15.6	1.50	639	6.21	5.34	2182	57.4	153.7	14.07	2249
	10	14	1.31	639	5.92	6.17	1967	57.9	205.7	14.67	2713
	20	14.5	1.55	629	5.64	5.01	2200	58.9	170.2	12.95	2513
NBSK – UCM high shear	0	14	0.93	505	2.24	2.68	1278	27.1	43.9	11.55	3000
	2	47	1.70	765	5.19	6.82	2633	58.6	258.9	.92	114
	5	49	1.76	765	6.32	6.53	2884	71.3	279	9.73	59
	10	54	1.92	772	6.41	8.22	2822	73.9	366.8	9.06	34
	20	74	1.88	799	7.17	7.55	3090	86.0	395.	8.85	23
NBSK – LC refining – 1.3 SEL	0	14	0.93	505	2.24	2.68	1278	27.1	43.9	11.5	3000
	128	21	1.35	620	5.72	5.39	1888	56.5	174.5	13.11	1447
	194	31	1.57	644	6.43	5.77	2144	62.2	192.1	11.19	572
	390	70	1.83	748	6.38	6.56	2789	70.5	276.8	8.08	23
	811	91	2.14	849	3.63	6.43	3097	58.7	255.5	5.84	13

UCM: ultra continuous mixer; WRV: water retention value; TEA: tensile energy absorption; NBSK: Nordic bleached softwood kraft pulp; LC: low consistency.

II. Effect of residence time in the UCM compression refiner on °SR, WRV, and strength properties and comparison with conventional LC refined pulp.



10. Effects of LC refining vs. UCM mixing on NBSK pulp’s strength properties, including burst index, tensile index, tear index, and air permeability vs. density. LC refining conditions were: applied energy of 0, 100, 200, 400, or 800 kWh/T; and specific edge load (SEL) of 1.3. UCM mixing conditions were 1.7, 5, 10, and 20 min at 10% pulp consistency for NBSK pulp (medium shear).



11. Effects of LC refining vs. UCM mixing on NBSK pulp's $^{\circ}\text{SR}$ vs. strength properties, including $^{\circ}\text{SR}$ vs. the following: burst index, tensile index, tear index, and air permeability. LC refining conditions were: applied energy of 0, 100, 200, 400, or 800 kWh/T ; and specific edge load (SEL) of 1.3. UCM mixing conditions were 1.7, 5, 10, and 20 min at 10% pulp consistency for NBSK pulp (medium shear).

meability, unlike LC refining, which always induces a large reduction in permeability as strength increases. The differences in the peripheral speed of the rotating elements (blades vs. discs) of 0.5 m/s with UCM mixing compared with 25 to 30 m/s with conventional LC refining explain the benefit observed in the case of the former.

In addition, residence time is a parameter that can be controlled in the UCM. This work has shown that an optimized effect at a fairly low residence time (1 to 5 min) can be obtained. All in all, the recommendations for treating NBSK fibers in this UCM device are as follows, in decreasing order of importance:

1. Blade profile: Standard shear
2. Mixing consistency: 8%
3. Rotation speed: 350 rpm
4. Residence time: from 0.5 to 5 min

CONCLUSION

Compression refining has long been discussed in the literature, with experiments in PFI laboratory refiners showing that, provided that the differential speed between the planetary rotor and the chamber is reduced to 0 (pure compression), strength development could be decorrelated

from $^{\circ}\text{SR}$. This very interesting behavior was unfortunately not achieved with a continuous device, and therefore not upscaled with a larger-capacity device.

With the UCM mixing technology, which is already used in other industries at high production throughputs of several tons per hour, it becomes possible to reproduce the very interesting behavior of the laboratory PFI refiner for NBSK pulp. We observed that very high tensile/burst strengths and tear can be obtained while keeping a low $^{\circ}\text{SR}$ and a permeable sheet. This new refining approach is, however, in its infancy, and as for LC refining technology, which required a number of developments to get it optimized, this new technology must be further optimized for pulp refining. The main limitations and challenges today for this technology are as follows:

1. Some modifications must be made to the machine so that the refining conditions can be altered inline without stopping the machine and changing the blade profile.
2. The results must be upscaled to check that similar results are obtained with a larger-capacity machine; this has already been done with a larger throughput machine, but needs to be done with an even higher-capacity machine.

3. Another critical question is to determine the best profile for different furnishes, as the optimized conditions for NBSK are not the same as those for other pulps. This work is being done in the framework of a current project running at the CTP.
4. The impact of this treatment on energy consumption needs to be further investigated, considering not only the refining energy but also its implications for the paper machine, and in particular, the electricity consumed to generate the vacuum for the vacuum box in the forming section and the gas consumed to generate the steam.
5. Finally, it is very difficult to find the first user willing to take a risk with a completely new technology.

The experiments reported here were performed using a laboratory UCM at 1 kg/h, although an industrial device already exists, which is not the case with the PFI mill. The UCM device will have to be adapted to our industry, but the upscaling process appears to be much more viable than for a PFI mill. This work has already started at CTP, with promising results and a significant potential for boosting the efficiency of paper production. **TJ**

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ABOUT THE AUTHORS

We studied this topic to improve refined pulp drainage and reduce papermaking energy consumption. This research complements a former research projet at CTP during which we observe the major influence of fiber flexibility on strength development.

The most difficult aspect of this study was finding technology allowing us to deliver only compression force. This was addressed by a large enquiry in the market, including other sectors of the industry.

Through this study, we found that conventional refining has several disadvantages. Our most interesting finding was the decorrelation between strength properties development and pulp drainability.

For mills, this technology offers significant possibilities for reducing energy consumption. Our next step is to investigate the behavior of others pulps and to scale up the technology.

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