Crushing: Is this any way to treat overthick hardwood chips for kraft pulping?

By M. MacLeod and A. Dort

Abstract: Chip crushing machines are used in some mills to destructure the overthick material from chip thickness screening into an acceptable form for kraft pulping. We recently developed a technique to measure the pulpability of crushed overthick chips versus that of accept chips of ideal thickness, and applied it to two softwood mill cases. This report describes the results of applying the same technique to three hardwood cases. In two of the cases (one aspen, the other maple), crushing efficiency was between 88% and 96% in reducing the generation of rejects in pulping, the intended effect of crushing. In the third case, on mixed hardwoods, crushing efficiency was only 16% in the "Before" case; after examination and maintenance of the machine, its efficiency was raised to 50%. As found earlier with softwoods, a potential danger lurks, however: damage to hardwood fibres during crushing was readily apparent, and relative to the pulps from reference chips, those from 100% crushed chips had significant deficits in fibre length and handsheet strength. Thus, crushing machines should be tested and maintained for high efficiency, and the proportion of crushed overthick chips in the total chip flow to a kraft mill should not exceed 20% (less than 10% would be better).

For the past three decades, thickness has been acknowledged as the key dimension for wood chips intended for kraft pulping [1-9]. In the 1980s, chip thickness screening systems came into wide use, and they are now considered an essential part of the design of most new kraft mills. As these systems have evolved, so has the equipment for processing the overthick chips rejected by the main accept screens. These "overs", typically the chips which will not pass through thickness screens having openings about 8 mm wide, are predominantly sound wood chips which are suitable for kraft pulping in every aspect other than thickness. Unfortunately, the overthick fraction can also carry contaminants: biological knots, rocks, metal, large pieces of bark, etc. Thus, an air density separation system is used to separate the overthick wood chips from the contaminants, primarily on the basis of specific gravity.

The overthick material which "flies" across an air density separator needs to be reduced to suitable thickness, typically in a chip slicer (a specialized form of chipper which cuts overthick chips into thinner particles), or a chip crusher (which compresses and destructures overs, rendering the crushed material comparable in kraft pulping performance to accepts of suitable thickness. This article deals with crushing machines and hardwood chips; an earlier one [10] addressed crushers and softwood chips.

Although we might describe an ideal wood chip for kraft pulping as 25 mm long, 25 mm wide, and 4 mm thick, wood chip furnishes in mills are always distributions of chip sizes. Our experience in analyzing the average thickness distributions of softwood chips being fed to the pulping systems in 20 bleachable-grade kraft pulp mills is this: 7% < 2 mm, 80% 2-8 mm, and 13% > 8 mm. In five hardwood mills, the values were 7%, 82%, and 11%.

The undersized material can have an advantage in delignification rate, but that is usually offset by penalties in yield (at a given kappa number), average fibre length, and pulp strength (especially with softwoods) [6,11]. It is always best to minimize the amount of undersized material.

If overthick chips are destructured or fissured rather than sliced, their "effective thickness" [4] in kraft pulping is reduced, and they function as thinner chips which liquor can penetrate more easily. Bryce and Lowe [12] described this outcome when testing a novel crushing machine on hardwood chips; they also provided a useful summary of the development of chip crushers, but none of the machines from that era achieved commercial viability.

In the 1990s, industrial machines for crushing overthick chips became available; they are called conditioners or crackers by their manufacturers. They crush the overthick chips by destructuring the wood, reducing the effective thickness [13-15] and allowing better penetration of cooking liquor into the wood. The roll faces of a typical crusher are shown in Fig. 1.

Once overthick chips have been crushed, classification by thickness is of little use. Simple visual inspection isn't much better. Some chips which still measure as overthick may be destructured enough to pulp just like chips of ideal thickness,

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TABLE I. Kraft pulping conditions used in the three hardwood cases.

	Aspen	Maple	Mixed Hardwoods
Active alkali [a], %	16.6	19.0	16.0
Sulphidity, %	29.0	29.0	28.0
Liquor:wood, L/kg	3.7:1	3.7:1	4.0:1
Maximum temperature, °C	168	168	170
Time to T_{max}, min	90	90	90
H-factor to reach 15 kappa	1300	1200	1900

[a] As Na_2O on o.d. wood.
Chip pre-steaming: three cycles of three minutes each at 138 kPa, exhausting to atmospheric pressure between cycles.

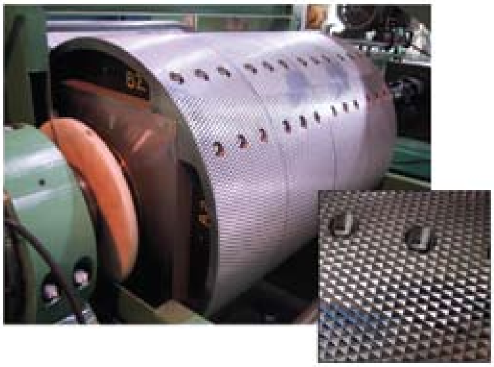

FIG. 1. Chip crushing machines have two parallel horizontal rolls whose surfaces have pyramidal projections (inset).

TABLE II. Thickness distributions of the chip samples in the three hardwood cases.

	Aspen			Maple			Mixed Hardwoods		
Size	Accepts	Uncrushed	Crushed	Accepts	Uncrushed	Crushed	Accepts	Uncrushed	Crushed
< 2 mm	7.4	0.7	8.6	6.1	tr	1.1	5.4	0.1	1.2
2-8 mm	88.2	5.4	39.7	87.2	6.0	21.0	87.7	7.9	28.3
> 8 mm	4.4	93.9	51.7	6.7	94.0	77.9	6.9	92.0	70.5

while others have escaped destructuring and will generate rejects upon pulping. Note that with hardwood chips, the rejects versus kappa number curve bends sharply upward just above the normal range of kappa targets (i.e., 12-16). Thus, going to a kappa number above ~20, for whatever reason, has the potential to increase rejects generation dramatically, even with chips of proper thickness. This effect is far worse with overthick chips.

The research described here follows on from that reported earlier for softwoods [10], but with three hardwood chip furnishes from mills: (1) aspen, (2) maple, and (3) mixed eastern Canadian hardwoods (mainly maple). The same experimental approach was taken as before. In addition, we devised an "efficiency factor" to rate the ability of a crushing machine to render overthick chips into properly pulpable material, and we examined crushed overthick chips microscopically to visualize how the destructuring occurs within the wood.

EXPERIMENTAL APPROACH

Chip Sampling and Kraft Pulping Techniques

Our technique was described in detail earlier [10]. It requires three streams of material to be sampled at a mill: (1) unprocessed overthick chips going to the crusher, (2) crushed overthick chips coming from the crusher, and (3) accept chips before addition of the crushed overs. We fractionate the accepts to retain only 2-8 mm thick chips, now called reference chips. Two conventional kraft cooks are done in a 20L forced circulation digester, using normal bleachable-grade pulping conditions corresponding to the operating practice in the mill being examined, see Table I. In each cook, the digester volume is split in half with stacked baskets. One cook tests reference chips (R100) and an 80/20 mixture of reference chips and crushed overs (C20). The other cook tests crushed overs (C100) and an 80/20 mixture of reference chips and uncrushed overs (U20).

Twenty percent of uncrushed overs mixed with 80% reference chips represents a "worst-case scenario". One hundred percent crushed overs tests whether such material pulps just as well as prime accepts (i.e., the reference chips). Twenty percent crushed overs mixed with 80% reference chips represents a "probable highest loading" of crushed overthick chips.

The cooked material from each stacked basket was processed separately into pulp [10]. Pulp yields and rejects were measured, and kappa numbers were determined on screened pulps. Rejects did not pass through 0.15 mm wide slots on a vibrating flat screen. In a mill, rejects would be a combination of knotter rejects and screen rejects. Further testing of the unbleached pulps usually included optical fibre length analysis (Kajaani FS-200), PFI beating, preparation of standard 60 g/m^2 handsheets, and measurement of physical properties according to PAPTAC Standard Methods.

Thickness Classification of the Chips in the Three Hardwood Cases

We used a Domtar classifier to measure the chip thickness distributions of the three types of chips in the three mill cases, Table II. In each case, the accepts were then fractionated to provide 2-8 mm "reference" chips, thereby removing small proportions of < 2 mm and > 8 mm chips. Note that crushing always shifted the thickness distribution toward thinner material.

RESULTS

Case 1 – Aspen

The aspen reference chips required an H-factor of 1300 to cook to 15 kappa number, giving a total pulp yield of 53.8% with negligible rejects. From uncrushed overthick chips (the U20 case), the rejects were 1.69%, Fig. 2; multiplied by five, the rejects from 100% uncrushed overs would have been ~8.5%. From crushed overs (the C20 case), the rejects were 0.20%, a nine-fold decrease from the U20 result. From 100% crushed overs (C100), the rejects were 0.61% – a little less than the 1.0% calculated by multiplying the C20 result by five, and more than a ten-fold reduction relative to the (calculated) U100 case.

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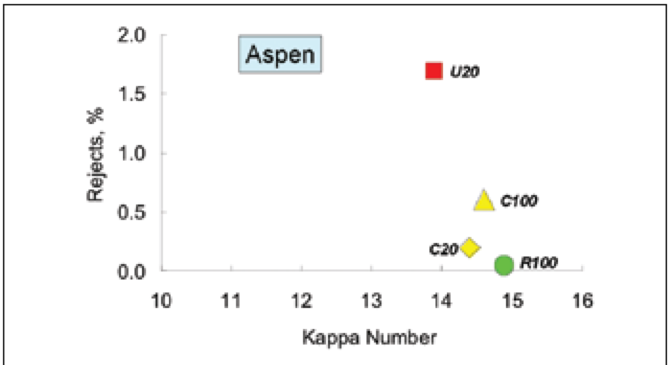

FIG. 2. With aspen, crushing of overthick chips brought the rejects down from about 1.7% to 0.2%, a nine-fold decrease. Pulping of reference chips generated a negligible amount of rejects.

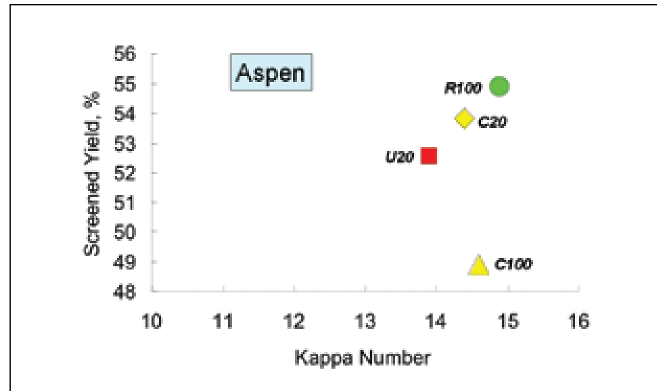

FIG. 3. Screened pulp yield at 14-15 kappa was ~55% from R100 aspen chips, but lower depending on the type and amount of overthick chips.

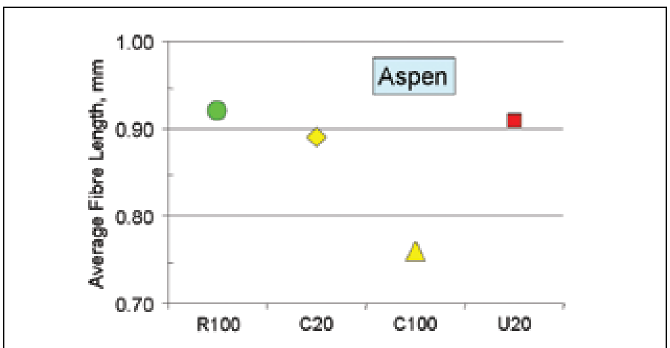

FIG. 4. A significant deficit in average fibre length was measured in unbleached aspen pulp from 100% crushed chips. When 20% crushed chips were pulped with 80% reference chips, the decrease in average fibre length was ~20% of the R100 to C100 decrease.

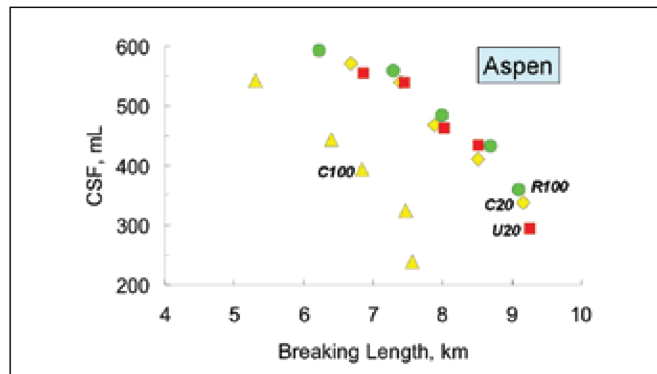

FIG. 5. Tensile strength at a given freeness was highest for the aspen pulps containing no fibres from crushed overs. The C20 case was almost indistinguishable from the R100 and U20 cases, but the C100 pulp was significantly worse.

The kappa number range was less than one unit. The mill's crusher was doing a very good job of converting the overthick chips into properly pulpable material.

Screened pulp yield versus kappa number, Fig. 3, illustrates the complementary picture – the highest screened yield came from reference chips (R100), followed by the C20 and U20 cases. The C100 case had an unusually high yield deficit (-6%). Part of the reason may have been the relatively high proportion of <2 mm material in the crushed chips. Also, it may have been contaminated with more decayed wood than the other chip fractions. In the four other cases we have examined to date, the average yield deficit between the R100 and C100 materials has been 2.5%.

In length-weighted average fibre length, Fig. 4, unbleached aspen pulp from reference chips (R100) was highest at 0.92 mm, and that from 100% crushed chips was lowest at 0.76 mm. The U20 case was comparable to the R100 case, the C20 case only marginally lower. These results indicate that crushing of overthick chips may cause significant damage to the wood fibres, which is then echoed by fibre length impairment in the kraft pulps made from them. The difference between the R100 and C100 values (0.16 mm) was greater than the typical fibre length loss along a hardwood kraft mill's entire fibreline [16].

In the C100 case, the tensile strength of the unbleached pulp was more than 1 km lower than the other three cases, and it was the worst of the group in terms of freeness, Fig. 5. Clearly, the crushing of wood fibres had a significant effect on the physical performance of the pulp fibres made from them. Fortunately, the C20 case indicated that the effect remained marginal up to that proportion of crushed chips.

In Bauer-McNett classifications, pulp from the reference chips had the highest proportion of 28/48 material, Table III, the largest fraction in any of the aspen pulps. The C100 pulp was clearly inferior: it had significantly less 14/28 and 28/48 material, and significantly more material in the 48/100, 100/200, and P200 fractions.

Case 2 – Maple

While operating on maple chips, the same three types of chip samples were collected at the same mill as in Case 1. Note that in thickness classification, the crushed overthick maple chips had ~26% more material still in the > 8 mm fraction than was true with aspen, see Table II – the maple chips appeared to be more resistant to the harshest stresses in crushing.

In this case, an H-factor of 1200 was required to reach 15 kappa number with reference chips; the corresponding total pulp yield was 48.2%, with negligible rejects. From uncrushed overthick chips (the U20 case), the rejects were 0.81%, Fig. 6; multiplied by five, the rejects from 100% uncrushed overs would have been ~4.1%. From crushed overs (the C20 case), the rejects were negligible. From 100% crushed overs (C100), the rejects were 0.17%. The kappa range was only 1.3 units. Crushing of overthick maple chips was so efficient that it virtually eliminated rejects in the C20 cooks. Hence, at 15 kappa, crushing provided a yield gain of 0.8%;

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TABLE III. Bauer-McNett classification results from unbleached aspen pulps made in case 1 (% of total mass)

	R100	C20	C100	U20	Average	σ
R14	0.1	0.1	0.1	0.1	0.1	0.0
14/28	4.1	3.0	**0.8**	3.6	2.9	1.5
28/48	64.0	60.9	**46.5**	61.2	58.2	7.9
48/100	22.8	24.7	**30.4**	24.0	25.5	3.4
100/200	2.0	2.6	**5.4**	2.4	3.1	1.6
P200	7.1	8.8	**16.9**	8.8	10.4	4.4

The C100 values in **bold** are outside the standard deviations calculated for the four cases.

TABLE IV. Bauer-McNett classification results from unbleached maple kraft pulps made in case 2 (% of total mass).

	R100	C20	C100	U20	Average	σ
R14	0.4	0	0	0.1	0.1	0.2
14/28	0.2	0.1	0	0.1	0.1	0.1
28/48	27.7	26.9	**22.6**	28.1	26.8	3.0
48/100	44.5	44.7	45.3	**45.9**	45.1	0.6
100/200	8.0	8.2	9.4	8.2	8.5	0.6
P200	17.3	20.1	**22.7**	17.5	19.4	2.5

The C100 and U20 values in **bold** are outside the standard deviations calculated for the four cases.

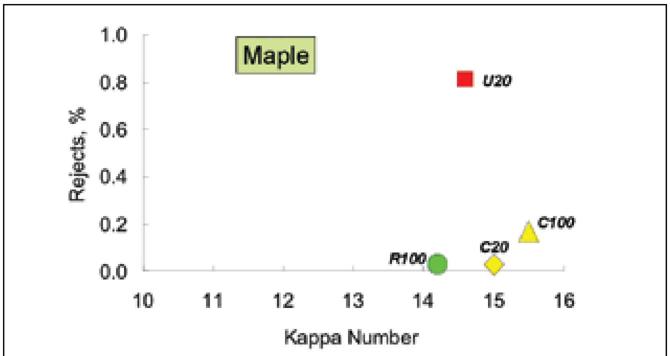

FIG. 6. With maple, crushing of overthick chips brought the rejects down from ~ 0.8% to only a trace amount.

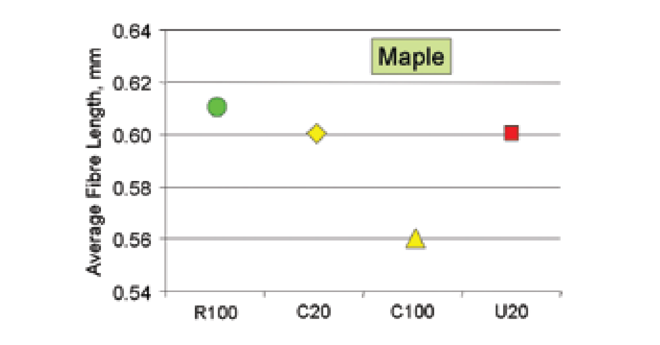

FIG. 7. There was a significant deficit in average fibre length in the unbleached maple pulp from 100% crushed chips.

in the absence of crushing, that difference would have been rejects instead.

We did another set of cooks at kappa 11-12. In the U20 and C100 cases, the generation of rejects was lower due to longer cooking time, but the overall ranking of the materials was the same as at 15 kappa.

In length-weighted average fibre length, Fig. 7, unbleached maple pulp from reference chips (R100) was highest at 0.61 mm, and that from 100% crushed chips was lowest at 0.56 mm. The U20 and C20 values were only 0.01 mm lower than the R100 value. The pattern was the same as that with the aspen pulps.

Plotting freeness against breaking length showed that the C100 case was the worst of the group, and that the C20 case was only slightly worse than the R100 one, Fig. 8.

In Bauer-McNett classifications, pulp from the reference chips had the highest combined amount of 14/28 plus 28/48 material, Table IV; the U20 pulp was comparable. The C20 pulp was slightly deficient in 14/28 material. The C100 pulp was significantly lower in 28/48 material and higher in P200 fines.

Case 3 – Mixed Hardwoods

The same chip sampling approach described in Cases 1 and 2 was taken at a mill operating on mixed eastern Canadian hardwoods. An H-factor of 1900 was required to reach 15 kappa number with these reference chips; the corresponding total pulp yield was 50.2%, with negligible rejects. From uncrushed overthick chips (the U20 case), the rejects were 1.7%, Fig. 9; multiplied by five, the rejects from 100% uncrushed overs would have been ~8.3%. From crushed overs (the C20 case), the rejects were 1.4%. From 100% crushed overs (C100), the rejects were 5.1%.

Whereas crushing was able to reduce rejects generation by a factor of about ten in Cases 1 and 2, the result in Case 3 was poor – rejects decreased by only 0.26% from the U20 chips to the C20 chips. This prompted a close examination of the crushing machine, followed by maintenance work to bring it back to intended operating conditions. We then repeated our sampling and pulping work, and found that in the "After" case, the U20 rejects were at 1.33%, but the C20 rejects had decreased to 0.66%, a significant improvement.

Among the unbleached pulps in both the "Before" and "After" cases, we saw the same patterns in average fibre length, tensile strength, freeness, and Bauer-McNett fractionation as described above in Cases 1 and 2. The C100 pulp was always the worst in the group, R100 always the best, and the C20 and U20 pulps were close or equal to R100 pulp.

DISCUSSION

The primary job of a chip crushing machine is to convert the overthick chips into ones which will cook just like accepts of suitable thickness, thereby minimizing a mill's exposure to rejects generation in kraft pulping. Using our technique, this capability can be measured accurately. To further simplify the results, we propose the concept of a "Crushing Efficiency Factor", defined as follows:

Crushing Efficiency Factor, % =
{1 -(C20 rejects/U20 rejects)} x 100

In Case 1 on aspen chips, for example, rejects generation from the C20 material was 0.20% from wood; from the U20 material, it was 1.69%. Thus, the efficiency factor was {1 – 0.12} x 100) = 88%. In Case 2 on maple chips, the crushing efficiency factor was 96%.

In Case 3, the "Before" factor was 16%, a number so low as to immediately point the finger at an inadequate chip crushing operation. In the "After" version, the effi-

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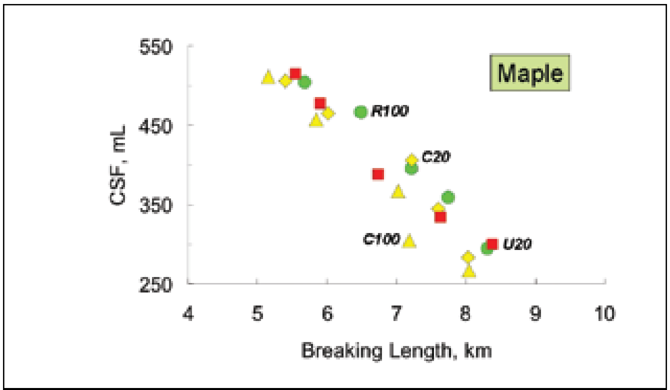

FIG. 8. Tensile strength at a given freeness was highest for the maple pulps containing no fibres from crushed overs. The C20 case was slightly worse than the R100 case, but the C100 pulp was significantly worse.

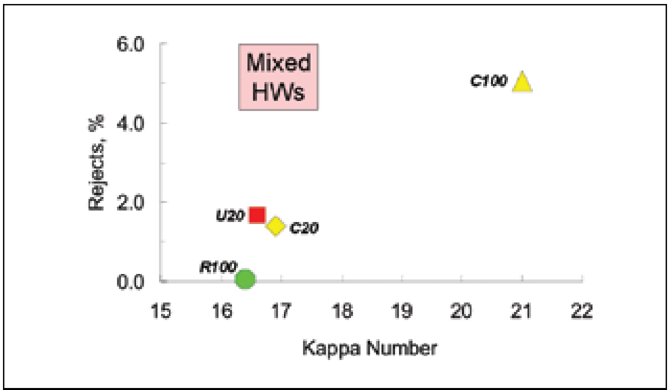

FIG. 9. With mixed hardwood chips, crushing of the overs reduced the rejects level only modestly, from 1.7% (U20) to 1.4% (C20). Pulping of the C100 chips generated about 5% rejects and shifted the kappa number four units higher.

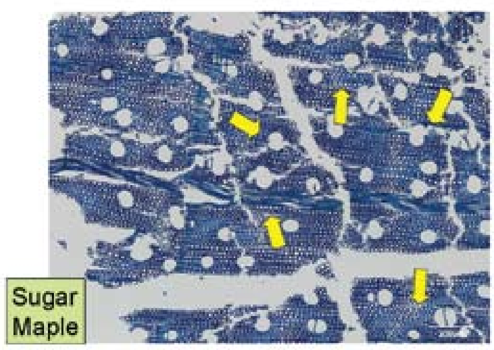

FIG. 10. This photomicrograph of a crushed maple overthick chip shows major grain-direction cracks through the middle (vertically) and in the lower half, and many small cracks near vessel elements (yellow arrows).

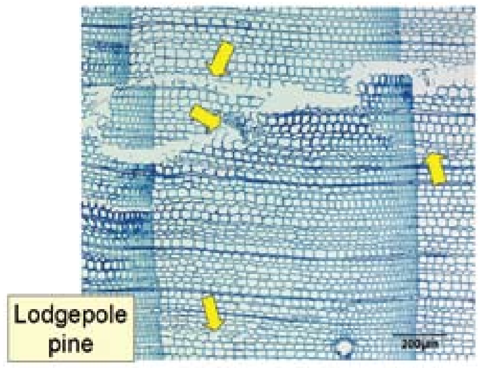

FIG. 11. This photomicrograph of a crushed lodgepole pine overthick chip shows a major crack (upper half) and many small cracks scattered throughout the cross-section (yellow arrows). Note especially the fracture of cell walls in thin-walled earlywood fibres at crack boundaries.

ciency had climbed to 50% – still not ideal, but a significant improvement. Further work is needed to bring this crusher to high efficiency.

Retrospectively, we calculated crushing efficiency factors for the softwood cases described earlier [10]; the values were 78-97%, depending on the exact case. Overall, then, we concluded that most of the crushing operations we have examined to date, whether on hardwoods or on softwoods, were running at high efficiency.

We also examined crushed chips microscopically to look for direct evidence of destructuring. Figure 10 shows an example with sugar maple, Fig. 11 with lodgepole pine. We have looked at several other species as well: Douglas fir, western red cedar, and aspen. In all instances, the macroscopic fracturing of the wood in the grain direction is clear, seen as the large, white "rivers" traversing the cross-sectional photomicrographs. More interesting is the evidence of cell wall deformation and rupture in all cases. With softwoods, this is particularly obvious in thin-walled earlywood fibres; the thicker-walled latewood fibres remained largely intact. With hardwoods, note how small fractures often radiate toward or away from vessel elements. It is easy to connect this visible cell wall damage to the inferior fibre length distributions and handsheet strength properties measured in the kraft pulps made from crushed chips. Although these observations are qualitative, they confirm what our eyes alone cannot – crushing machines inevitably damage wood fibres. This damage will then be reflected in inferior pulp made from such chips, something that can never be repaired inside a kraft mill.

Our technique – based on measuring the generation of rejects in kraft pulping – appears to be the most direct, reliable, and quantitative way to determine the efficiency of overthick chip crushers.

SUMMARY

Crushed overthick hardwood chips were pulped alone and as 20% of a mixture with 2-8 mm reference chips. In two of the cases (one aspen, the other maple), crushing efficiency was between 88% and 96% in reducing the generation of rejects, the intended effect of the treatment. Only the cooks of reference chips consistently gave negligible amounts of rejects at kappa 15. As found earlier with softwoods, a potential danger lurks, however: damage to hardwood fibres during crushing was readily apparent – relative to the pulps from reference chips, those from 100% crushed chips had significant deficits in fibre length and handsheet strength. In the third case, on mixed hardwoods, crushing efficiency was only 16% in the "Before" case; after examination and maintenance, the machine's efficiency was raised to 50%.

ACKNOWLEDGEMENTS

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Résumé: Dans certaines usines, on utilise des broyeurs de copeaux pour déstructurer les copeaux refusés du tamisage par épaisseur en une forme acceptable pour la mise en pâte kraft. Nous avons récemment élaboré une méthode permettant de mesurer l'aptitude à la mise en pâte de copeaux refusés du tamisage broyés par rapport à celle des copeaux acceptés d'épaisseur idéale, et nous l'avons appliquée à deux cas de résineux dans les usines [PRR 1636]. Le présent rapport décrit les résultats de l'application de cette même technique à trois cas de feuillus. Dans deux de ces cas (tremble et érable), l'efficacité du broyage a permis de réduire la production de refus de tamisage de 88 % et 96 %, l'effet visé du broyage. Quant au troisième cas (feuillus mélangés), l'efficacité du broyage n'a été que de 16 % dans le cas « avant ». Après examen et entretien du broyeur, l'efficacité a atteint 50 %. Comme pour les résineux, il existe toutefois un danger : on pouvait voir facilement le dommage fait aux fibres de feuillus pendant le broyage. En ce qui concerne les pâtes produites à partir des copeaux de référence, celles faites à partir de 100 % de copeaux broyés présentaient un déficit important quant à la longueur de la fibre et à la résistance de la formette. Pour obtenir une efficacité maximale, les broyeurs devraient donc faire l'objet d'un essai et être entretenus et la proportion de copeaux refusés du tamisage broyés alimentés à une usine kraft ne devrait pas dépasser 20 % (moins de 10 % serait encore mieux).

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