A new approach to mechanical pulping — pretreatment of chips by normal-to-grain compression prior to refining

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Abstract

The effect of two chip-compression methods — transaxial compression and screw pressing — on thermomechanical pulping of softwood chips was investigated. Both chip-compression techniques improved pulp properties while reducing refining energy. However, the results indicated that the static trans-axial compression of chips was more advantageous than the screw compression by better maintaining the pulp quality while lowering specific-energy consumption. The static compression involving a single compressive force produced less fiber breakage, while the screw pressing was relatively more destructive to the chip structure because of its dynamic nature involving a combination of several mechanical forces.

Introduction

The present work was initiated as an attempt to improve the refining efficiency in mechanical pulping. It is understood that there are two major mechanical forces, shear and compression, involved in chip refining, and they occur simultaneously. Conceivably, the shear action is dependent on the compression. For a given rotation speed of the rotor of a refiner, the shear action acting on a wood matrix or a fibrous mass increases with an increase in compression force. The fact that the current refining technology does not permit independent control over the two operating forces may represent a technical barrier hindering efforts to improve the relationship between energy consumption and pulp quality in mechanical pulp production.

Understandably, the compression and shear have their own unique functions in chip refining. Our experience indicates that static compression, a densification process, mainly creates fiber deformation and cell-wall delamination and little fiber separation *(1)*. In chip refining, the fiber separation and fragmentation (peeling, cutting, splitting, and fibrillation) would be the contribution derived from the shear action. Ideally, to obtain the best possible pulp quality with a minimum energy requirement, the compression action should precede the shear action to create a favorable condition (particularly the delamination of cell wall in the S_1 layer) for the latter. As said earlier, such a process configuration cannot exist in the present refining technology.

However, to remedy this technical difficulty, an independent stage of preconditioning of chips can be established prior to refining. It is known that any mechanical force of significant magnitude acting on a wood matrix can generate cell-wall delamination, particularly in the S_1 region, due to the inherent differential microfibril organization of the lamellae. In this study, we compared two preconditioning techniques—screw pressing and static compression—on the refining characteristics of softwood chips in a thermomechanical process.

EXPERIMENTAL

Chip treatment

Fresh chips of black spruce/balsam fir (about 80/20 ratio) were obtained from a pulp mill. The chips as received had a moisture content of 48%. They were first classified using a laboratory Rader disc classifier to obtain chips with a nominal thickness of 4–6 mm, minimizing the variation in chip thickness. This fraction represented approximately 26% of the unclassified chips. The chips used in the study contained no oversized particles, and chips with visual evidence of knots or decay were rejected. The majority of the chips measured about 2.5 cm or less in length, with varying width. All chips were washed before use.

In platen pressing, chips in green condition were arranged in single layer, grain parallel to the flat press plates, and compressed between two 60 × 60-cm smooth stainless steel plates by means of an hydraulic press (60 cm × 60-cm platens). The pressure applied was the maximum working pressure of the press, which was 1945 psi (13.41 MPa). Due to the variability in chip thickness, the surface of the chips carrying the load was not determined. The loading rate was approximately 5 cm per minute. Due to the limitation of this pressing process, neither the actual strain of compression on the chips nor the energy used was determined. For the same reason, the pressing was conducted repeatedly to ensure that all chips were sufficiently compressed. In the process, the thickest chips, which carried most of the applied load, were removed first, and the thinner ones, which had been pressed to a lesser extent, were re-pressed and removed subsequently.

The chips used in screw pressing were steamed under atmospheric pressure for 10 min before being pressed by means of the PREX system of a Sunds Defibrator CD-300 pilot unit. The system has a volumetric compression ratio of 2:1.

Refining

Thermomechanical refining was conducted using a Sunds Defibrator CD-300 pilot unit, of which the refiner was equipped with a stator plate R3801 and a rotor plate R3809. The refiner is driven by a 200-hp motor with 3565 rpm. The general pulping conditions were: digester temperature of 126°C, 17% discharge consistency, and a production rate of about 0.7 kg/min. The precompressed chips and the untreated ones were fed through the digester’s window and steamed for 20 min at 126°C followed by pressurized refining at that temperature. The chips to be screw-pressed were fed through the plug screw (PREX system) in a usual TMP process with 10-min steaming at 126°C followed by pressurized refining. Note that a longer steaming time was used for the platen-pressed and the unpressed chips to compensate for the 10-min atmospheric steaming through which they had not undergone. Pulps having various degrees of freeness were produced in single-stage pressurized refining.

Chip characterization

The experimental chips used for size-distribution analysis and water-uptake measurements were air-dried to a moisture content of 35–40%. Chip screening (5 min) on a Williams classifier was carried out in duplicate, using about 2 kg of air-dry chips. The water uptake of each Williams fraction was determined at room temperature by soaking approximately 250–300 g of chips in tap water for 48 hours under atmospheric conditions. The moisture uptake was determined, in duplicate, as the percentage of the oven-dry weight of the chips used.

Pulp characterization

Unscreened sample pulps were used in all cases, and pulp latency was removed in hot water in a Domtar disintegrator before use. Freeness measurements, handsheet formation, and optical and mechanical property determinations were conducted in accordance with TAPPI test methods. Pulp fractionation was made using a Bauer–McNett classifier. Pulp rejects were determined by means of a Pulmac Master Screen (Pulmac Instruments Intl., USA), while the fiber length was measured using a Fiber Quality Analyzer (FQA) (OpTest Equipment Inc., Canada). The pulp used for the FQA measurements was prepared by macerating match-sized sticks of chip in a mixture of hydrogen peroxide and acetic acid (1:1 v/v) at 75°C for about 4 hours (or until the material can be readily disintegrated into individual fibers by a gentle shaking with glass beads).

RESULTS AND DISCUSSION

Characteristics of compressed chips

As seen in **Table I**, screw pressing caused substantial reduction in particle size, while platen pressing produced little breakdown of chips when compared with the untreated chips. Visual observation of the screw-pressed chips indicated that the particles were twisted and ruptured under the combined efforts of compression, shear, tension, and torsion of the screw. **Figure 1** shows the cross-section view of torsion failures in screw-pressed fibers. The effect of torsion was particularly evident with large and long chips. According to Hearn *(2)*, the shear stress caused by torsion in a thin rectangular material is related to its dimension: Wide and thick materials undergo higher shear stress than the narrow and thin ones. In static compression, where a single compressive force is involved, partial fiber separation along the grain was noticeable, and little breakdown into smaller particles was observed. **Figure 2** demonstrates the intracellular failures, presumably in the S_1 region, of the platen-pressed fibers. When a single layer of chips was pressed between two smooth flat platens, the load was applied more or less uniformly over the entire chip surface, and the chips extended laterally across the grain. On one occasion, it was observed that under a pressure of about 80 kg/cm^2, a sulfonated chip extended its transversal width up to 120% without breaking down. In fact, shearing fluffs up the chip structure, while compression densifies it. Pressing chips, having a small range in thickness, in a single layer is an ideal situation. In reality, when multiple layered chips are compressed on an industrial scale, the pressing effects will undoubtedly be less desirable, resulting in nonuniform loading and, consequently, fiber breakage because of the uneven stress distribution in the huge mass of chips. This technical problem will be a challenge for the industry to develop an efficient way of compressing chips.

Table I. Characteristics of spruce/balsam fir chips (4–6-mm fraction)

	WILLIAMS CLASSIFICATION FRACTION					
Chip size	**1 1/8 in.**	**7/8 in.**	**5/8 in.**	**3/8 in.**	**3/16 in.**	**<3/16 in.**
Weight percentage, %						
Not pressed	8.2	24.1	41.2	25.2	1.3	…
Screw pressed	0.7	8.6	28.7	41.1	15.8	5.1
Platen pressed	7.5	23.6	40.9	26.6	1.4	…
Water retention, %						
Not pressed	148	148	148	148	148	…
Screw pressed	296	294	297	294	323	447
Platen pressed	288	281	284	287	290	…
Length-weighted fiber length, mm						
Not pressed	2.89	2.82	2.88	2.85	2.86	…
Screw pressed	2.30	2.71	2.60	2.67	2.73	2.02
Platen pressed	2.80	2.79	2.82	2.80	2.81	…
Length-weighted fines, % (FQA)						
Not pressed	0.98	0.99	0.98	0.96	0.99	…
Screw pressed	2.51	1.49	1.42	1.10	1.40	4.24
Platen pressed	1.14	1.16	1.13	1.11	1.14	…

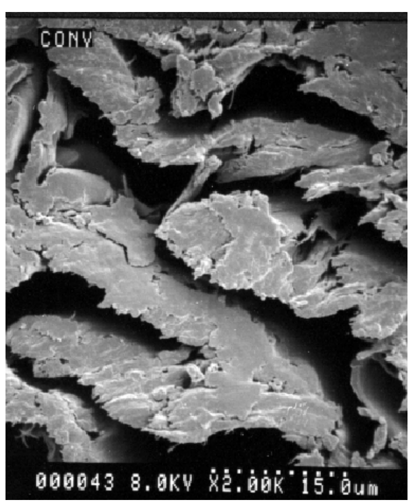

Figure 1. Cross-section view of torsion failures in screw-pressed fibers.

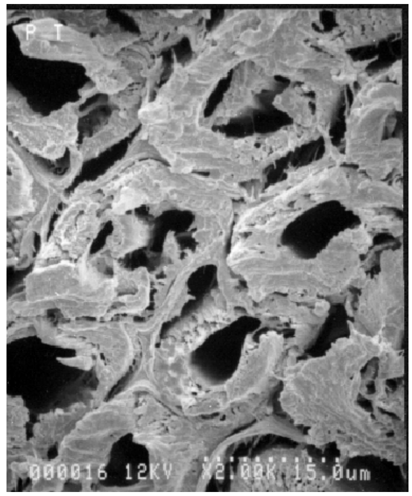

Figure 2. Intracellular failure of platen-pressed fibers.

The effect of mechanical pressing on chip structure was characterized by measuring the water absorption capacity of the pressed particles. The water uptake value gives an indication of the characteristics of their internal structure. It was observed that the water retention capacity of both types of compressed chips was nearly double that of the untreated ones (Table I). However, the screw-pressed chips were slightly more absorbent than the platen-pressed ones because of their higher apparent specific surface; they had a fluffy nature.

Fiber breakage is a major concern with screw compression of chips *(3, 4, 5, 6)*. As seen in Table I, the mechanical compression of chips reduced the average fiber length, which was particularly evident with screw pressing. The drop in mean fiber length for the screw-pressed chips ranged from about 4% to 20%, while that for the platen-pressed chips ranged from 1% to 3%, in comparison with the untreated ones. Regarding the screw pressing, the most important effect on chip structure is the generation of fine particles (<3/16 in.), which represented about 2% of the total chip mass. These fine particles had an average fiber length about 30% less than that of the untreated fibers. How these fine particles would behave in refining remains a concern over the resulting pulp quality. Another consideration that deserves our attention is that some of the fibers in the compressed chips might have been substantially weakened by the mechanical pressing, reducing their resistance to the refining forces and thus resulting in an increase in fines content in the pulp. These physical aspects of compressed fibers needed to be further investigated.

The FQA fines represent the fraction containing the macerated fibrous particles of less than 0.2 mm in length. Interestingly, the largest (1 1/8 in.) and smallest (<3/16 in.) fractions of the screw-pressed chips had the highest fines (2.51% and 4.24%, respectively), corresponding to the marked drop in their mean fiber length (Table I). The substantial increase in fines for the largest chips might indicate that some fibers in these chips were in fact broken under the severe shear and tension actions of the screw. As stated previously, the large particles sustained a greater shear stress than the small ones, resulting in more severe fiber breakage. Regarding the fine (<3/16 in.) fraction of the screw-pressed chips, due to the reduced mean fiber length of its component fibers, this would undoubtedly contribute to the increase in fibrous fines content in the resulting pulp. Compared with the untreated chips, the increase in FQA fines ranged from about 40% to 150% for the screw-pressed chips (except the 3/8-in. fraction, which had an increase of about 15%) and 15–17% for the platen-pressed chips.

Refining energy

The energy values reported here refer to the refining energy, excluding the energy consumed by chip preconditioning, which was not determined due to the particular limitation of our laboratory pressing technique. However, about 17 kW·h/ton can be applied to conventional chip press units *(7)*. As shown in **Fig. 3**, chip compression resulted in a statistically significant (95% significance level) reduction in refining energy when compared with the nontreated material. Over a freeness range of 100–200 mL, the energy saving for the screw-pressed chips was 10–20% compared with the untreated chips. In the same freeness range, the energy saving for the platen-pressed chips was even more significant, ranging from 18% to 25%. Intriguingly, as seen in Table I, the marked reduction in chip size, the increase by 2% (of the total chip mass) fine particles of less than 3/16 in. (<4.8 mm) in width, and the substantial improvement in water-uptake capacity brought about by the screw pressing did not reduce the refining energy consumption to the same level as that for the platen pressing. This implies that the physical changes imparted to the chips by the screw press were dissimilar to those produced by the static compression, which were comparatively more beneficial in terms of energy saving based on the freeness–energy relationship.

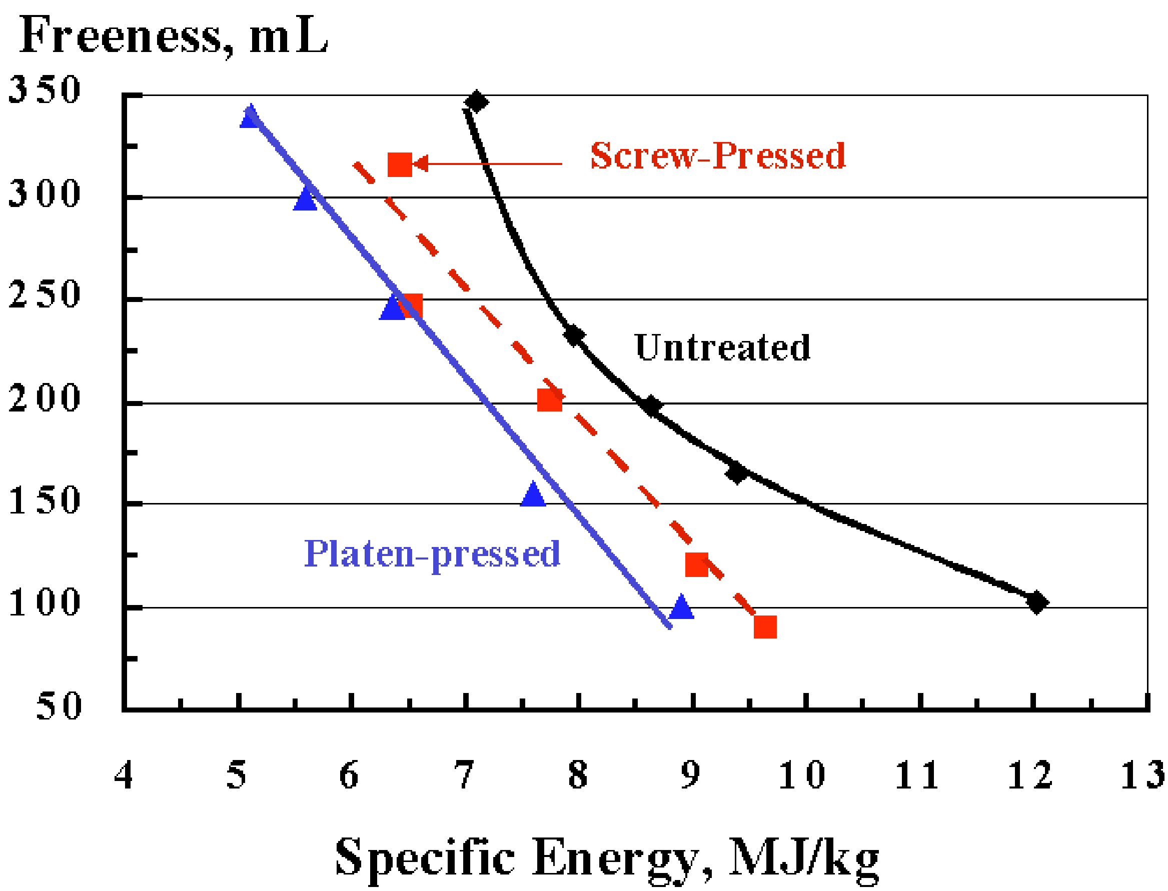

Figure 3. Pulp freeness as a function of specific refining energy.

Characteristics of fibers

The rejects content retained on a 0.1-mm slot screen is a good indication of refining efficiency. **Figure 4** shows that refining of the screw-pressed chips resulted in a high shive content, similar to that for the untreated chips. On the other hand, refining of the platen-pressed chips gave lower shive content, which was statistically different (99% confidence level) from that of the other two pulps. At a refining energy of 9 MJ/kg (ca. 100 mL CSF), the platen-pressed chips showed a 0.4–0.5-point drop in rejects compared with the untreated and screw-pressed pulps. It is speculated that the increase in rejects for the screw-pressed chips might be attributed to the probability of fiber weakening or breakage under the high shear and tensile stresses, or to the production of fine chip particles, resulting in an increase in chunky particles in refining.

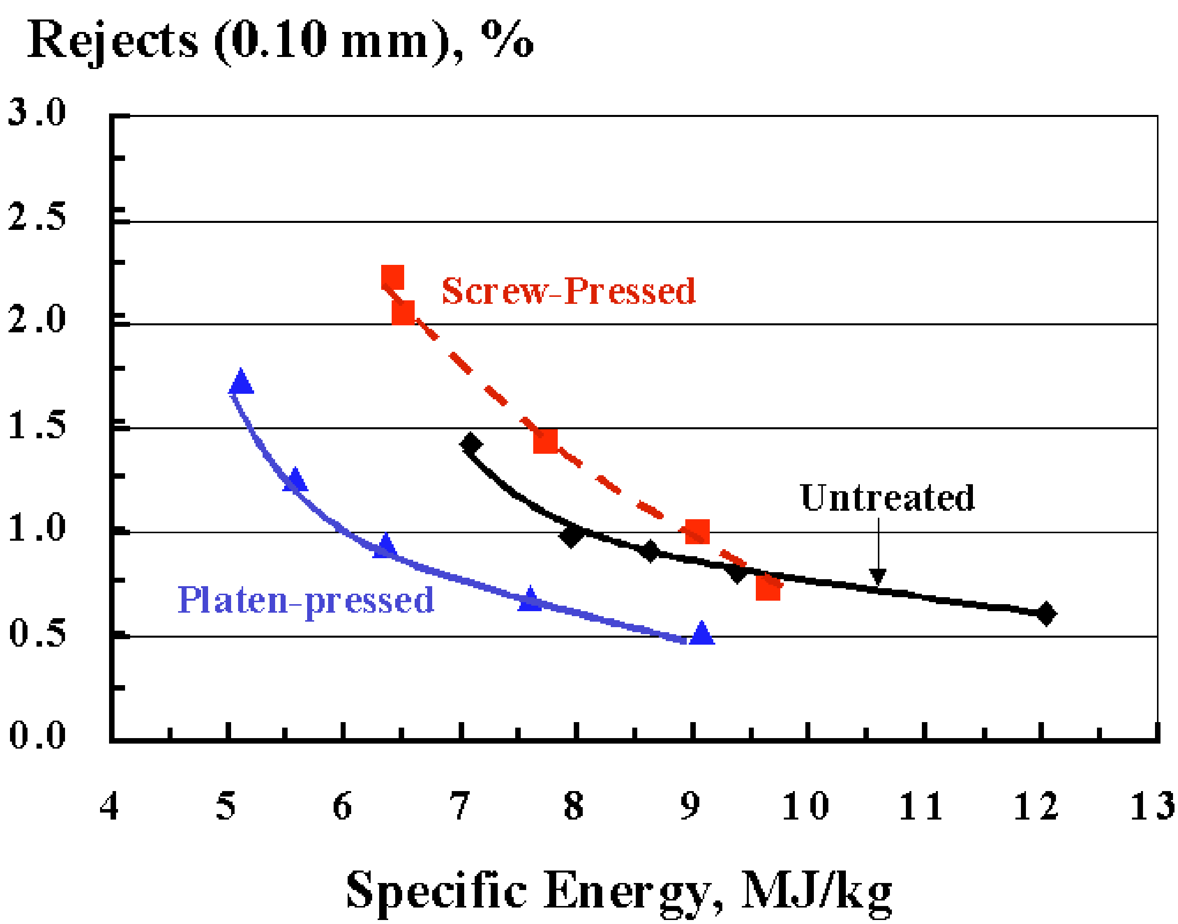

Figure 4. Pulp rejects as a function of specific refining energy.

Results for fines content in **Fig. 5** show that the screw-pressed pulps had about a 3-point higher fines content (Bauer–McNett, P-200 fraction) than the platen-pressed and untreated pulps, which were comparable in fines content. The increased fines content for the screw-pressed pulps might be attributed to fiber breakage in screw pressing, particularly in the largest (1 1/8 in.) and smallest (<3/16 in.) fractions of the compressed chips, as noted earlier.

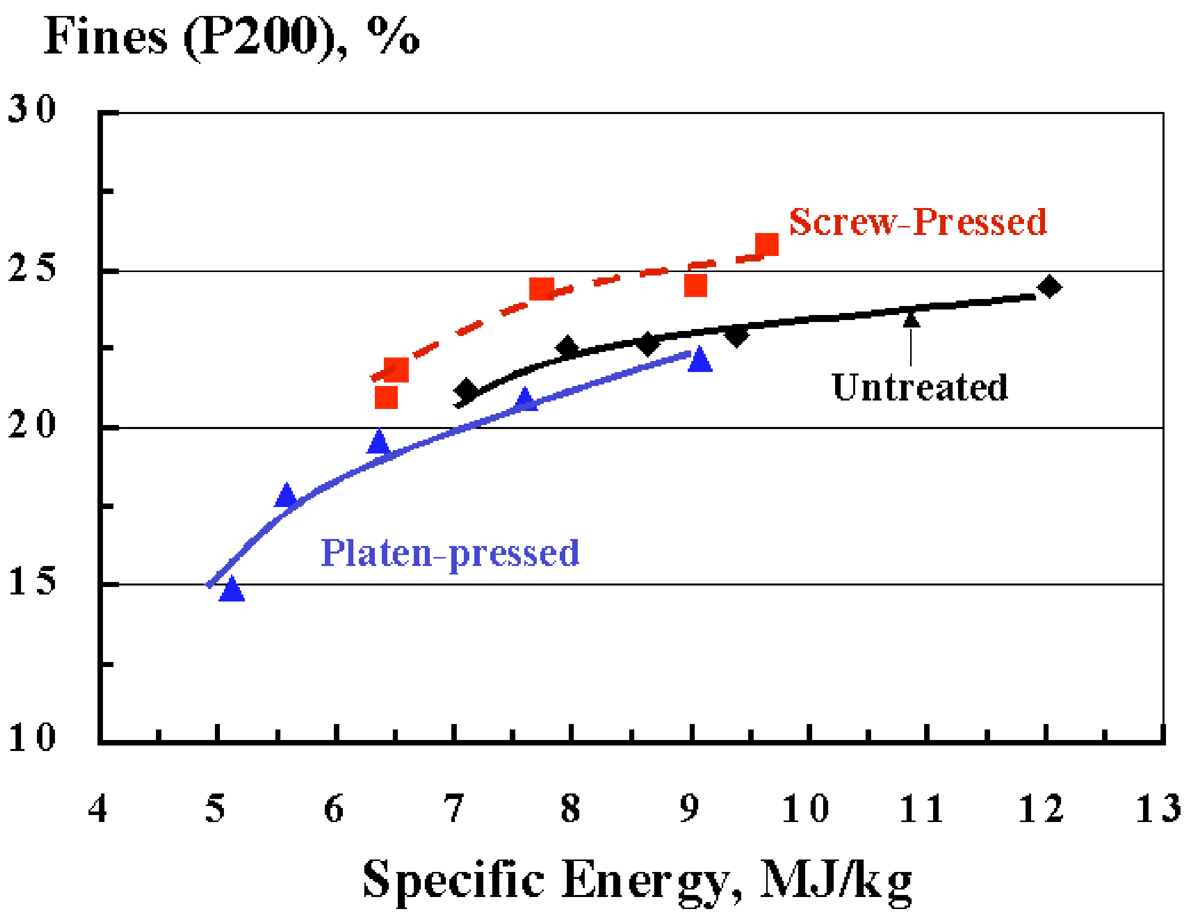

Figure 5. Pulp fines as a function of specific refining energy.

Handsheet properties

The results for tensile index in **Fig. 6** show that the platen-pressed pulps had the highest tensile index, the untreated pulps the lowest, with the screw-pressed pulps in between. However, **Fig. 7** shows that both types of compressed pulps had similar burst index, which was statistically better (95% confidence level) than that for the untreated pulp. Meanwhile, the tear-index results in **Fig. 8** show that the platen-pressed chips had a particularly high response at low energy (5–7 MJ/kg) compared with the screw-pressed and the untreated pulps. Intriguingly, this tear index dropped sharply with increasing refining energy. The reasons for the marked fall in tear index for the platen-pressed pulps are not clear at this point. Note that the screw-pressed pulps had a tear index that was similar to that of the untreated ones. Other fiber characteristics and handsheet properties can be found in the literature *(8)*.

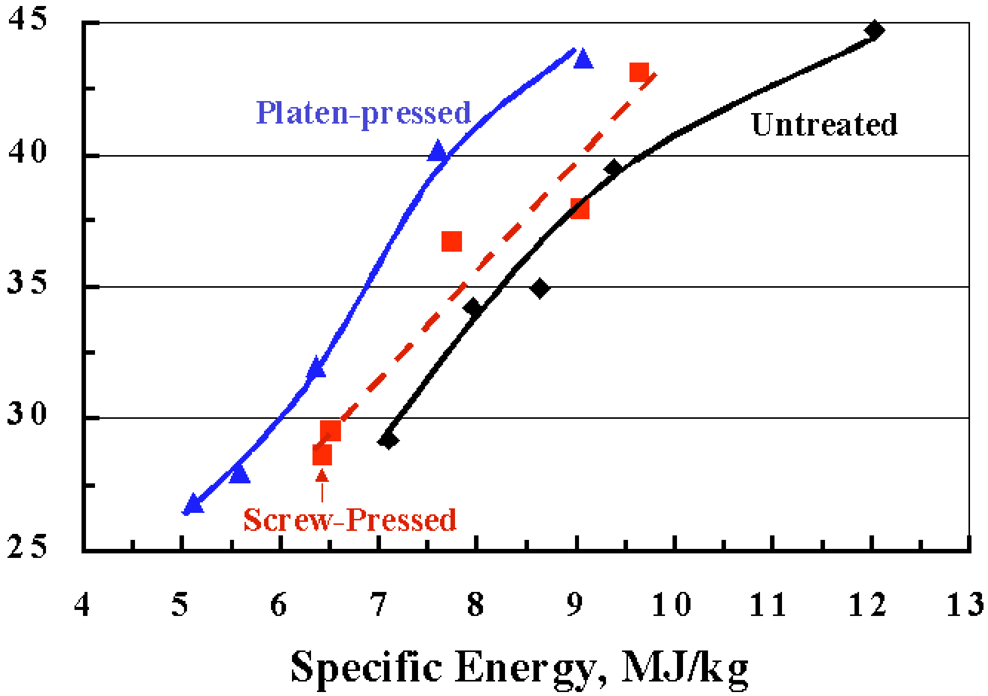

Figure 6. Tensile index as a function of specific refining energy.

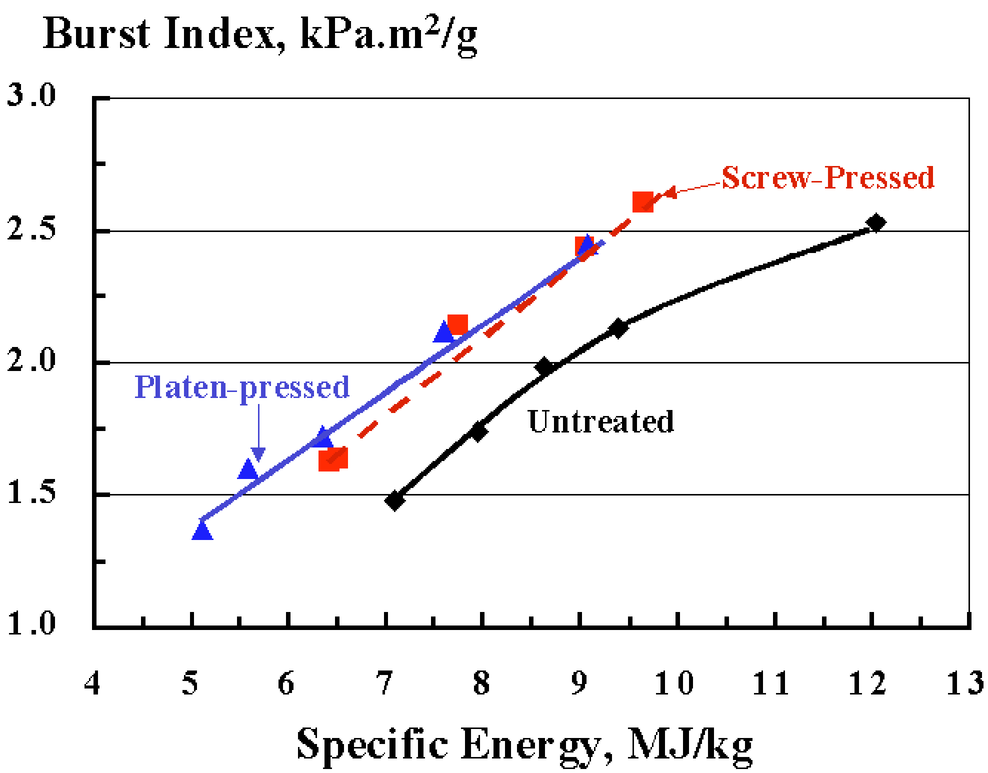

Figure 7. Burst index as a function of specific refining energy.

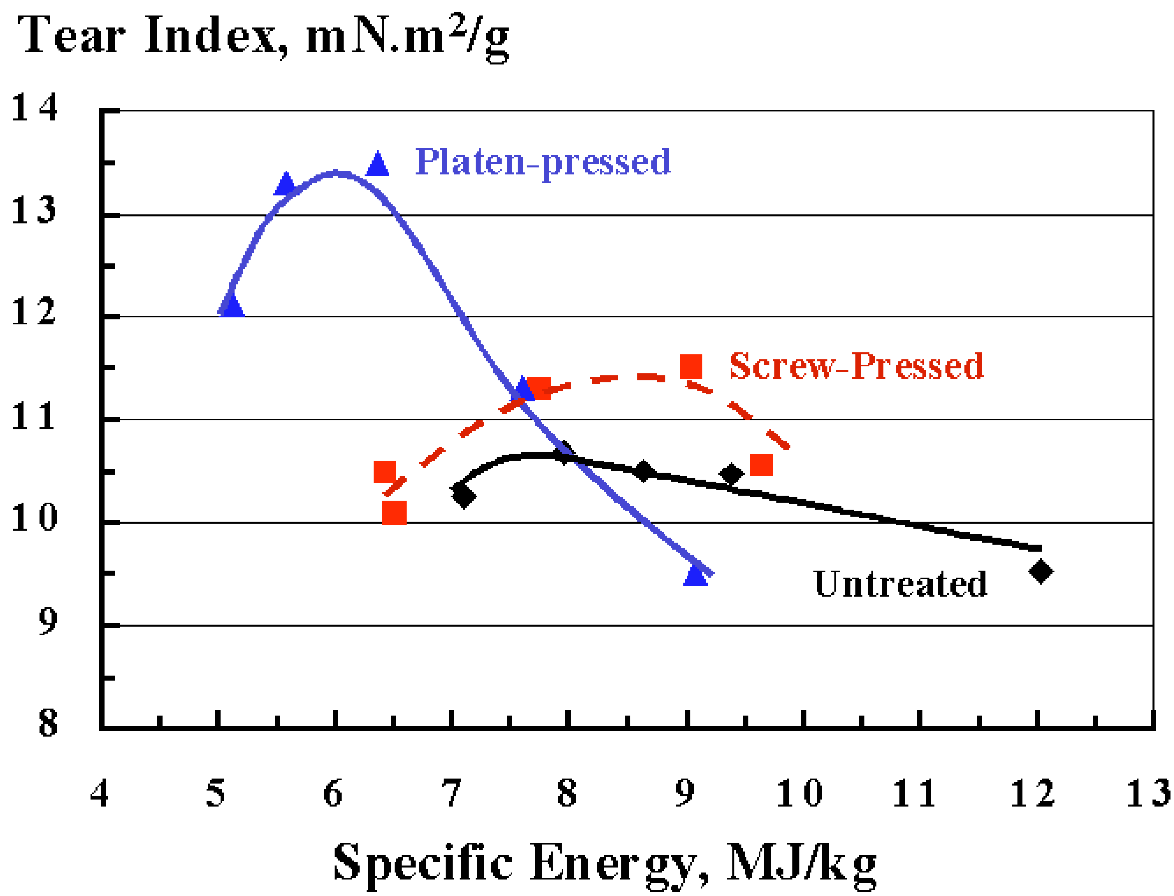

Figure 8. Tear index as a function of specific refining energy.

Concluding remarks

Preconditioning of chips by mechanical pressing is an efficient way of improving the relationship between energy consumption and pulp quality *(4, 5, 7, 9, 10, 11, 12)*. The results of this study show that the effect of chip compression on refining depends on the technique used. We learned that compression force deforms (e.g., delamination of cell wall) the wood matrix while the shear force fragments it. In screw pressing, a number of mechanical forces act simultaneously on the wood matrix. The modes of failure in the matrix under such a multiple-force situation would be difficult, if not impossible, to control. Ideally, in chip refining the compression action should precede the shear to create a favorable situation for the latter. Unfortunately, it is impossible to establish such a condition in a refiner for obvious reasons.

The results from this study clearly demonstrate that a separate chip-preconditioning stage by means of mechanical compression can create a favorable condition for refining, resulting in improved pulp quality and a reduction in specific refining energy.

Preconditioning of chips by static compressing across the grain was found to be more advantageous over the conventional screw pressing in terms pulp quality and energy savings. Frazier and Williams *(10)* reported that static axial compression also produces fiber separation, particularly in the buckling lines, and cell-wall delamination in the S_1 layer. While the refining results from the axially compressed wood blocks are interesting, the application of this method to industrial chips of varying forms is difficult for practical reasons. Furthermore, it is known that axial compression resistance of a wood matrix is several magnitudes greater than the transverse compression strength.

Roll pressing, a dynamic mechanical action, used in chemical pulping *(12, 13, 14)* represents a simple technique for improving pulping efficiency. However, the major concern of this method is the possible fiber damages that occur when the chips are pressed over a small area under extremely high stress concentration. Additionally, the dynamic roll-pressing action takes place from one end of the chips to the other, creating high stress concentration and conceivably resulting in fiber breakage in the wood matrix. Understandably, the risk of fiber breakage would be even more severe when the rolling action is perpendicular to the grain.

The refining trials in this study were conducted using a rotation speed of 3565 rpm, which is relatively high for a 30-cm refiner. Refining at this high intensity can create a tremendous shear stress on the fibrous mass, accentuating the fragmentation effect on the fibers. The idea of chip preconditioning is based on a new vision of chip refining, which posits that attention should be focused on deformation of the wood matrix (i.e., chip compression) rather than on the shear fragmentation action. This is particularly important when preconditioned chips are used. Further investigations in this respect are needed to validate such a perception. While the static compression of chip perpendicular to the grain seems to be a desirable approach for producing refiner mechanical pulp with improved property and reduced specific energy consumption, the industrial application of this technique remains a challenge for the engineering experts.

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