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Reclaiming fiber from newsprint dry methods

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Abstract

Economical and environmental considerations suggest the desirability of recycling old newspapers to newsprint in urban areas, using methods with reduced demand for process water. In bench-scale experiments, we successfully dry-fiberized old newspapers at moisture contents from 2 to 52%. Handsheets of acceptable appearance were made from dry-processed fiber by both air-laid and water-laid processes. Water-laid handsheets of dry-fiberized furnish had less strength than did handsheets from wet-processed fiber. Air-laid handsheets yielded lower density and has less tensile strength compared to water-laid handsheets of the same fiber. Methods for increasing tensile strength are suggested.

Introduction

United States publishers presently use 40% of the total world consumption of newsprint (more than 12 million tons annually); 57% is imported from Canada, and another 1% to 2% is imported from Scandinavia. The cost of these imports is about $5 billion annually [1,2]. At present, old newspapers (ONP) represent both a serious solid-waste problem and a valuable resource [3–6]. Although approximately one-third of all newspapers printed are recycled, ONP still accounts for almost 7% of the solid-waste landfill burden [3–5]. Legislation requiring the recycling of ONP has been enacted in several states, and literally hundreds of bills are being considered in other states and municipalities [6].

With the continuing improvement of deinking and secondary fiber recovery systems, a natural market for ONP lies in the manufacture of newsprint. Innovative papermakers around the world have demonstrated that significant fractions of ONP can be used in newsprint with acceptable results using existing technology [7–10]. Impediments to broad adoption of this approach are

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(a) the high cost of backshipping ONP to newsprint mills, often located many hundreds of miles from the urban source of the ONP [11], and (b) the large capital investment and massive water demands inherent in converting ONP to newsprint by conventional means. Water demand is not a problem at the present sites of virgin newsprint mills, but it is a serious limitation to urban siting of recycle mills. If we could choose the best of all worlds, we would convert ONP to newsprint in urban areas using "mini-mill" processes involving little or no net demand for water and simple, low-cost machinery. Given the need, one is almost compelled to ask, "Is there any reality in such an attractive fantasy?"

The purpose of our research is to explore this conceptual territory. Specifically, our objective is two-fold; first, to explore (bench-scale) methods for liberating fiber from ONP with minimal use of water and with minimal damage to the fiber, and second, to explore papermaking techniques that would yield an acceptable newsprint using less water than do current methods, based on machinery that is less costly to purchase and operate than current machinery. Deinking is not a part of this study. Our research is funded by the American Newspaper Publishers Association (originators of the mini-mill concept), the Environmental Protection Agency, and the USDA Forest Service. All participants recognize the risk associated with a radical departure from established, effective methods—particularly in a mature industry. Yet, contemporary resource changes and social needs to reduce landfill waste argue the merits of another look at alternatives—risky or not [12].

In this paper, we report three experiments; two are related to mechanical fiberizing of dry or semidry newsprint, and the third describes progress in the production of a newsprint-weight handsheet by an air-forming technique. These experiments describe what we have observed on the "road not taken" in prior developments. The work has not been highly successful, but concepts and processes that may make urban conversion of ONP to newsprint not only feasible but highly attractive may yet exist.

Experiments and results

Screening test for fiberizing methods

The purpose of this initial experiment was to find a combination of machine type, feed source, and operating conditions that would be successful in liberating individual fibers for use as a furnish in subsequent forming of newsprint sheets. The ONP source (for the screening test and all experiments reported here) was a clean, never-printed, stub roll of virgin spruce finish – 75% groundwood and 25% chemithermomechanical pulp (CTMP). This stock entered the fiberizing process as either strips (cut to 75 by 500 mm) or "crumbs." Crumbs were prepared by hydropulping the roll stock, followed by bulk dewatering in a screw press, shredding, and drying to various moisture contents. This crumb pulp is intended to represent output of a wet-deink process. Moisture contents from 4% to 60% (by weight) are to be anticipated.

Based on our own earlier attempts with a variety of devices and on the experience of others [13], we selected three machines with very different actions for the first set of controlled fiberizing experiments. We hoped to generate a range of products that would point toward effective fiberizing concepts as opposed to optimizing a set of operating parameters. The machines were as follows:

(1) A laboratory 200-mm single-disk atmospheric refiner with three blade sets of various design. The refiner is powered by a 3.7-kW motor at 3,600 rpm. Blade gaps ranging from 0.05 to 1.25 mm were investigated.

(2) A 260 mm-diameter commercial hammermill in which a large number of articulated blades impact and abrade the furnish between the blade and a perforated screen. The blades rotate at 4,000 rpm; hole sizes of 3 mm and 1.5 mm were investigated.

(3) A commercial, variable-speed "deagglomerator" in which a single rotating impeller propels the furnish at high speed within a perforated basket. Particle size is reduced by repeated impact of the furnish against the basket surface until the furnish passes through the perforations. Impeller speeds are variable from 0 to 4,200 rpm. We selected hole patterns of 0.8 mm diameter, 28% open area, and 1.9 mm diameter, 51% open area; impeller speed was 900 rpm.

We were able to find a range of operating conditions for each of the three machines that produced a fiber fluff containing a high proportion of individual fibers. This fiber was generally mixed with paper fragments or fiber bundles, which we have called nits. To determine the yield of individual fibers and to separate fiber from nits for sheetmaking, the fluff must be screened or classified. We developed the apparatus depicted in Fig. 1 for this purpose.

Our initial measure of the quality of pulp obtained from disintegration and separation processes was the fiber length distribution of accepts as measured by a Kajaani FS-100 fiber length analyzer[1] [14]. The Kajaani instrument employs a narrow capillary tube that allows single fibers to pass through. It optically measures the length of each fiber in a very dilute sample composed of thousands of fibers. After a sample has been run, the instrument calculates distribution of fiber lengths and a weighted-fiber-length average in millimeters. Reduction in the percentage of long fiber in the furnish (seen as reduced weighted fiber length) is direct evidence of fiber damage in the fiberization process and predicts degradation in mechanical properties of handsheets [15–18].

Table 1 cites the operating conditions, yield, and weighted fiber length for the most successful 12 of 20 initial mechanical fiberizing trials and for the

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Nit-separator

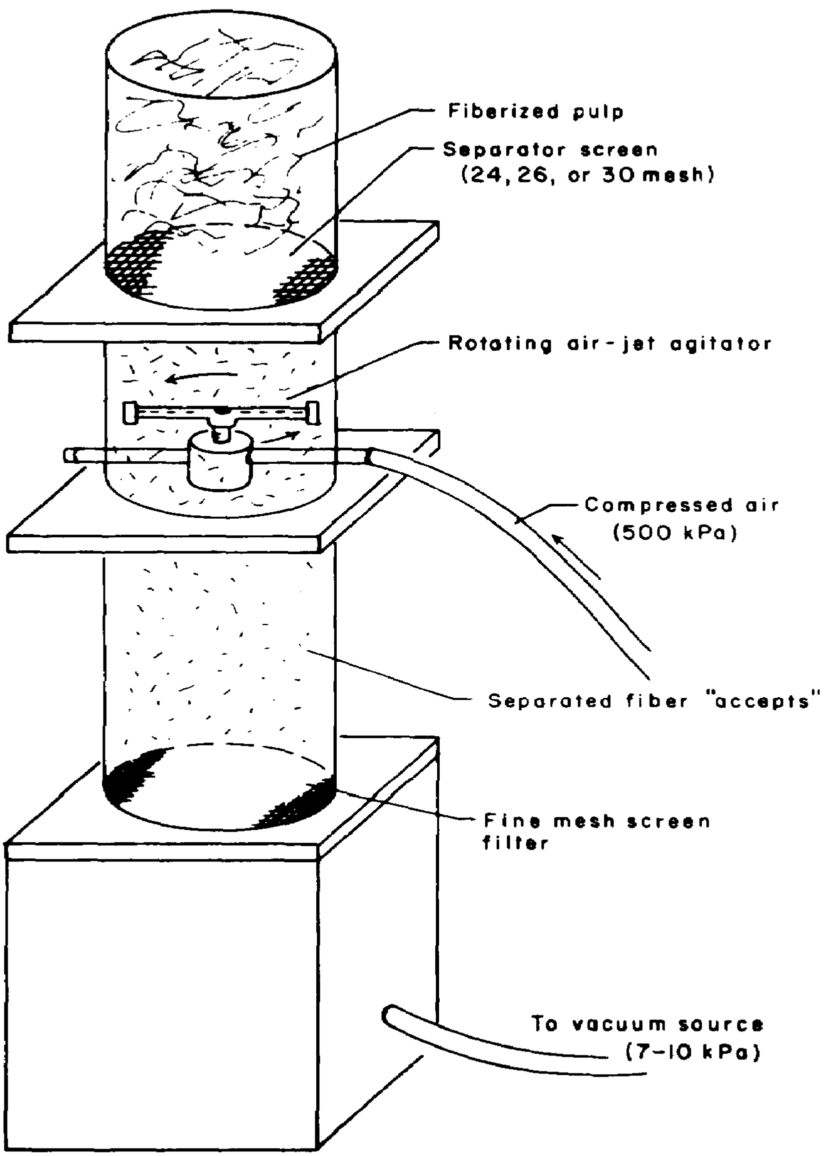

Fig. 1. FPL-designed nit separator. Fiber fluff is agitated by air jets to separate individual fibers from paper fragments and fiber bundles. Mesh sizes 24, 26 and 30 correspond to 707, 651 and 595 μm, respectively.

control (furnish disintegrated by gentle agitation in hot water (85°C)). Feed rate for all fiberizing processes exclusive of control and for the hammermill was approximately 50 g/min. The hammermill was fed at approximately five times that rate. Blade gap setting for all disk refiner trials reported in Table 1 was 0.13 mm. The table is arranged in order of decreasing resultant fiber length

TABLE 1

Selected screening trials of fiberizing methods

Fiberizing method	Feedstock	Moisture content (%)	Separator yield (%)	Fiber length[a] (mm)
56-Control[b]	Strip	7	100	1.26
74-Disk refiner #1 blade	Crumb	18	100	1.20
75-Disk refiner #1 blade	Crumb	18	72	1.20
71-Disk refiner #1 blade	Strip	16	82	1.18
72-Disk refiner #1 blade	Strip	16	100	1.18
50-Hammermill 3.0-mm holes	Strip	8	50	1.15
76-Disk refiner #3 blade	Crumb	18	69	1.02
52-Deagglomerator 0.81-mm	Crumb	4	98	1.00
holes	Strip	7	75	0.97
77-Disk refiner #3 blade	Strip	16	71	0.96
78-Disk refiner #3 blade	Crumb	4	81	0.90
80-Disk refiner #3 blade	Crumb	4	88	0.88
73-Disk refiner #1 blade	Strip	7	92	0.84
70-Disk refiner #1 blade				

[a]Weighted fiber length determined by Kajaani FS-100.
[b]Furnish disintegrated in hot water.

and shows a variety of yields ranging from 50% to 100%. In this experiment, the strong differentiation relating to machine type that we had anticipated did not occur.

Given the undifferentiated response from machine to machine and the ease of use, flexibility, and range of results obtained from the disk refiner, we have used the disk refiner almost exclusively for subsequent processing experiments. The high nit content of low-yield processes was apparent to the eye, but differences in fiber length were not. All high-yield products appeared equally good. The data suggest a tendency toward better fiber length retention for higher moisture content furnish. The most significant finding of this work is that either crumb or strip furnish can be mechanically fiberized with good yield and little loss of fiber length.

In the second phase of this experiment, fiber produced by the various means was formed into handsheets by the wet process described in the Technical Association of the Pulp and Paper Industry (TAPPI) Standard T205, press dried in accordance with methods described by Horn [19] at 135 °C at 700 kPa, and evaluated for tensile strength and tear resistance according to TAPPI methods T494 and T414, respectively. Figure 2 shows tensile strength index as a function of the weighted fiber length measured for the various methods. (Tensile index represents force per unit of specimen width per gram of fiber.) The highest strength value, at 1.26 mm weighted fiber length, is that for the control fiber liberated by gentle agitation in water. Results show the tensile

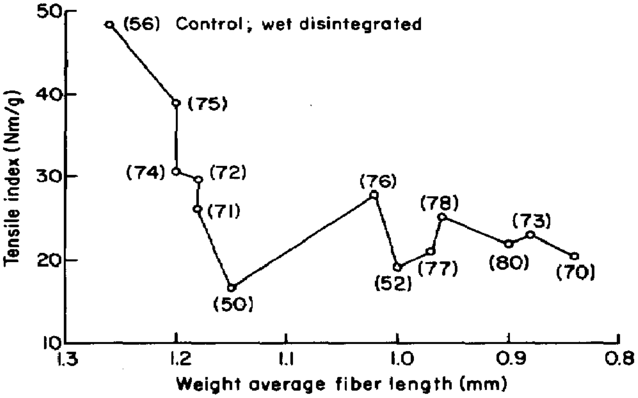

Fig. 2. Tensile index of TAPPI water-laid/press-dried handsheets made from fiber obtained in selected dry-fiberization processes. Fiber length measured by Kajaani FS-100. Numbers in parentheses correspond to fiberizing methods (Table 1).

TABLE 2

Strength properties of newsprint and recycled water-laid handsheets

Material	Fiber length[a] (mm)	Density (kg/m^3)	Tensile index (Nm/g)	Strain to failure (%)	Relative tear index[c]
Roll stock	–	640	39.0[b]	1.37[b]	120[b]
Control pulp[d]	1.26	776	48.2	1.42	100
Disk refined pulp[d]					
18% moisture content	1.20	630	38.8	0.73	91
4% moisture content	0.88	700	22.9	0.48	52

[a]Weighted fiber length determined by Kajaani FS-100.
[b]Geometric mean of machine-direction and cross-machine-direction properties.
[c]Expressed as percentage of control.
[d]TAPPI water-laid handsheets, press dried at 135°C, 700 kPa.

index dropping 46% as fiber length declines 7% from 1.26 to 1.18 mm. Reductions in fiber length below 1.18 mm show a less pronounced effect.

Barring a unique sensitivity to small initial reductions in fiber length, the results suggest a difference in the mechanically liberated fiber that compromises sheet tensile strength. Handsheets made from mechanically liberated fiber at fiber lengths of 1.20 mm and 0.8 mm had low strength, strain-to-failure, and tear index values compared to handsheets made from control pulp and virgin roll stock (Table 2). The clearly superior performance of the fiber processed at 18% moisture content compared with that of fiber processed at 4% moisture content suggests the potential for better results in fibers processed at still higher moisture content. The control pulp handsheets had higher strength properties than did the sheets from the roll stock as a result of the greater density and strength-enhancing qualities of press drying [20–22].

Effect of moisture content on fiber length and handsheet strength

We evaluated handsheets made by different fiberizing methods over a range of moisture contents from "as pressed" at 67% moisture content to ovendry at less than 4% moisture content. Quantities of crumb furnish were tumbled at 50 °C in a commercial drum-type dryer to obtain intermediate values of 52.5%, 42.5% and 31% moisture content (as well as ovendry). These furnishes were subsequently fiberized in the single-disk refiner using blade set 1 at a clearance of 0.13 mm. (Crumbs at 67% moisture content would not fiberize but tended to stick to blade surfaces in the refiner, which eventually stalled the motor). A control pulp was prepared by hydropulping roll stock in water at 20 °C. The relative fiber length of the pulps mechanically fiberized at various moisture contents are shown in Fig. 3. Increasing moisture content was clearly beneficial in promoting retention of fiber length; disk-refined fiber at 52.5% moisture content retained 97% of the length of the control fiber. The control pulp and the four pulps produced at ovendry to 52.5% moisture content were then formed into handsheets by TAPPI method T205, as in the previous experiment, and press dried at 135 °C, 700 kPa. Because of the high yield in this process, nits were included in the test sheets with no apparent effect.

Handsheets were evaluated for tear strength, tensile strength, stiffness, strain to failure, and energy absorption. Results for the four disk-refined pulps are shown in Table 3. The tear resistance for the best of our mechanically fiberized pulps was 93% of that for the control pulp. Tear strength tends to decline for the other pulps as fiber length decreases [15,16,18]. Strain-to-failure and tensile strength followed a similar pattern, but the highest value of each was limited to approximately 70% of that for the control pulp. Tensile energy absorption was 46% of the control for our best pulp, and it dropped to 25% of the control for the fiber produced at ovendry conditions. We conclude that although we have been successful in liberating fiber from crumbs at 52.5% mois-

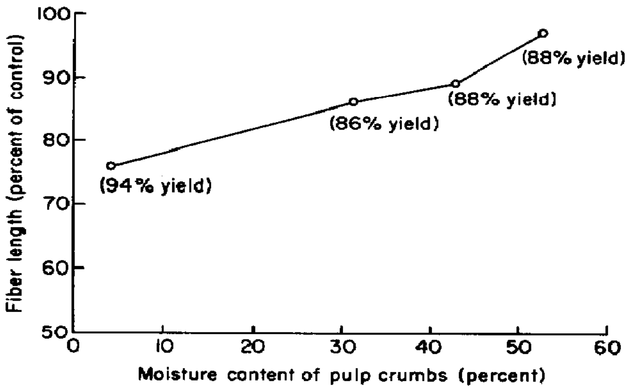

Fig. 3. Relative fiber length of pulps fiberized at various moisture contents in single-disk refiner. Reference is water-disintegrated control pulp. Numbers in parentheses specify separator yield.

TABLE 3

Effect of processing moisture content on fiber length and handsheet properties

Moisture content (%)	Fiber length (mm)	Handsheet properties (%)[a]				
		Tensile strength	Stiffness	Strain to failure	Energy absorption	Tear
52.5	97	69	79	70	46	93
42.5	89	59	67	60	33	72
31.0	86	63	77	71	44	79
4.0	76	57	76	48	25	43

[a]Shown as percentage of control handsheet values. TAPPI water-laid handsheets, press dried at 135°C, 700 kPa.

ture content with almost no loss of fiber length, we have not yet produced a fiber that can replicate the performance of the control furnish in terms of sheet strength or toughness.

Web formation

This experiment explored air-forming methods as an alternate means of web formation. The objective was to determine if the net demand for water in the recycling process can be reduced by use of forming means other than conventional wet-forming, which occurs at water to fiber ratios of 100:1 and higher (<1% consistency). It has long been known that webs with excellent formation can be made by air deposition of fiber at low moisture content (air-laid webs) [13,23]. These webs can be wetted with water and then dried under restraint to create hydrogen bonding between the fibers. The strength of sheets produced in this way has characteristically been less than that of sheets produced from water-laid webs. However, with the development of press-drying technology and its demonstrated ability to enhance the strength of webs with poor natural bonding potential [20—22], it is reasonable to ask if the combination of air-laid web formation and press drying can yield a recycled newsprint of acceptable strength [24].

Air-forming and water-forming methods

For this evaluation, a quantity of pulp was dry fiberized from crumbs at 25% moisture content in the disk refiner using Method 75 (see Table 1). With this fiber, we then formed a series of air-laid and water-laid handsheets varying the temperature of the forming or rewetting water, the forming substrate, and, because press-dry effectiveness has been shown to vary with sheet weight, the grammage. Our results showed the forming substrate for the air-laid webs had little effect on the outcome of the experiment. To simplify presentation, we report only four procedures that span the range of results: two water-laid methods and the best and worst of the air-laid methods.

Air-laid handsheets were made in an apparatus designed by the Forest Products Laboratory (Fig. 4). The fiber for one sheet is placed into the agitation chamber and the top of the chamber is sealed. A 7- to 10-kPa vacuum is applied to the plenum by an industrial vacuum source. The air jets are then alternately pressurized by 500 kPa compressed air, causing the fiber bundles to agitate and the individual fibers to shake loose from each other. As the fibers are separated, air flow carries them through the 16-mesh (1.2-mm) screen and down through the tower. The forming screen at the bottom of the tower retains the fiber as the air passes through creating a uniform web of fibers. The process takes approximately one minute. The web is then removed with the forming screen for rewetting and drying. In this experiment, webs were formed at 50, 70, and 90 g/m^2.

The rewetting procedure was found to be a significant variable for air-laid

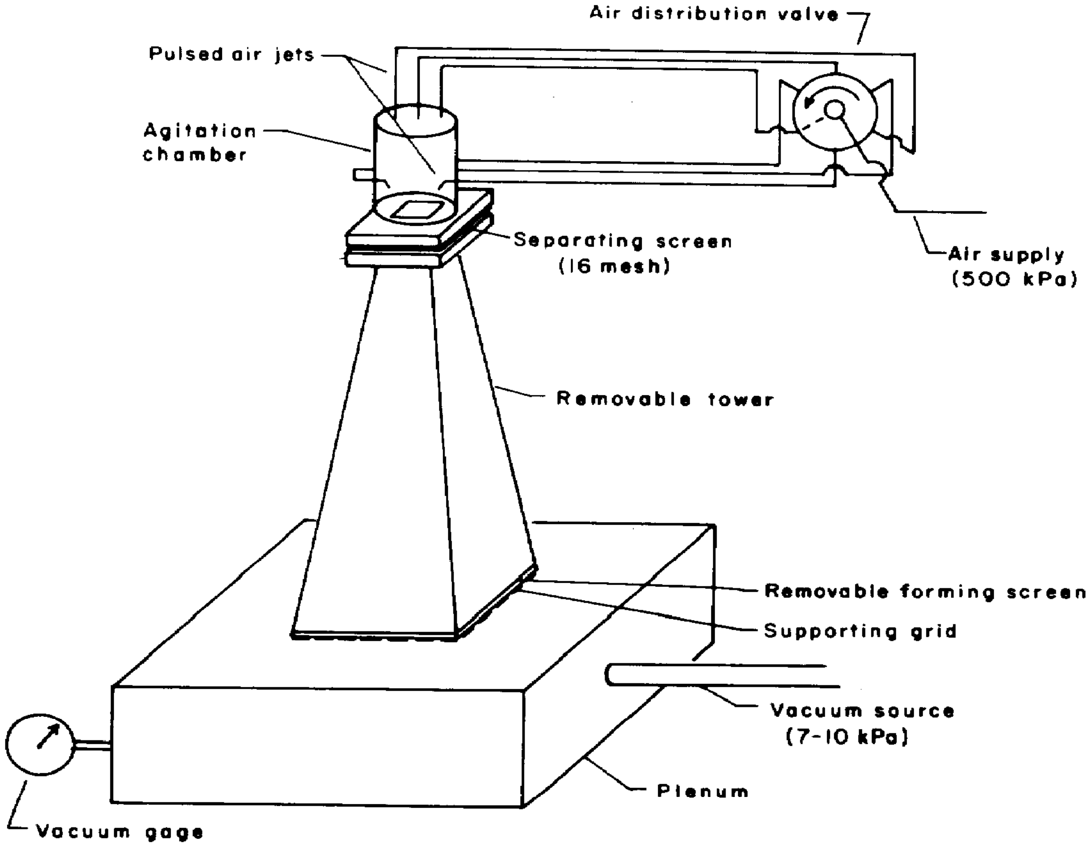

Fig. 4. Forming apparatus for handsheets. Fiber liberated in agitation chamber is drawn through 16-mesh (1.19-mm) screen and deposited to form web on removable forming screen.

webs. Air-laid handsheets wetted with cold water were rewet by placing the web, on its forming screen, onto a plastic grid in a shallow pan. The water level in the pan was just slightly above the top of the grid. The water was able to soak up into the web through the forming screen by capillary action. The water temperature was 19°C; wetting time was approximately 1 minute. Once wetted, the web was wet pressed between blotters at 3.0 MPa and subsequently press dried at 149°C, 3.0 MPa for 1 minute.

Air-laid handsheets wetted with hot water were treated in the same manner as handsheets wetted with cold water except that the temperature of the rewetting water was 55°C. After rewetting, the web was held in a saturated environment at 38°C for 1 hour to ensure thorough wetting of the fiber prior to wet pressing and press drying.

The temperature of the forming water was a significant variable in the performance of water-laid sheets (formed in a British sheet mold). To form cold-water-laid sheets, fiber for one sheet was mixed in 19°C water for 15 seconds. The slurry was then added to the sheet mold, diluted with more 19°C water, and drained to form the web. Webs were couched off the screen, wet pressed between blotters in groups of six, and press dried.

Hot-water-laid sheets were made in similar manner, but fiber preparation was modified in a manner intended to enhance fiber flexibility and remove latency [25] prior to forming. Fiber for six sheets was weighed out and mixed in 55°C water for 15 minutes. After the fiber was mixed, the fiber slurry was added to a doler tank and diluted with more 55°C water. The fiber was allowed to mix in the doler tank for an additional 45 minutes before forming, wet pressing, and press drying. The overall formation and appearance of the better air-laid and water-laid sheets were good to excellent. However, the air-laid sheets were subjectively inferior to the water-laid sheets in their appearance and characteristically exhibited a small number of pinholes not seen in the water-laid sheets.

Density and tensile strength results are shown in Fig. 5. The data show the superior performance of water-laid webs and the beneficial effect of hot water (and extended sorption time) relative to cold water.

Air-forming and liquid-forming methods

Another experiment provided a better understanding of the significant difference in performance of the webs made by air-forming as opposed to liquid-forming methods. The orientation and networking of fibers in an air-laid web is presumably different from that in a liquid-laid web. It is reasonable to ask if the reduced performance of air-laid webs is related to such differences in web structure. In this experiment, dry fibers were liquid laid, using ethyl alcohol as a forming medium.

The experiment involved three primary processes and four supporting methods. All used the same mechanically fiberized furnish made in the disk refiner

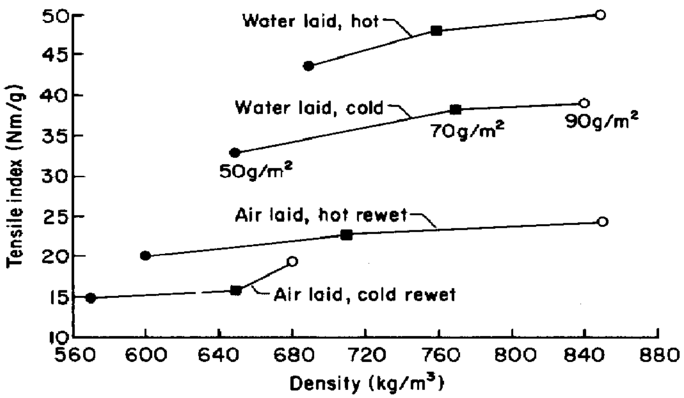

Fig. 5. Density and tensile strength of water-laid and air-laid handsheets weighing 50, 70, and 90 g/m^2. Temperature of forming and rewetting water was 19 °C (cold) or 55 °C (hot).

TABLE 4

Properties of air-laid and liquid-laid handsheets[a]

Web type		Tensile index (Nm/g)	Density (kg/m^3)	Fiber length[b] (mm)
A.	Hot-water-laid	44.8	723	1.00
B.	Air-laid	17.5	683	1.07
C.	Alcohol-laid	21.7	640	1.07
D.	Alcohol wash, air-laid	17.8	637	1.06
E.	Hot-water soak, alcohol wash, air-laid	23.6	660	1.04
F.	Hot-water soak, alcohol-laid	27.9	700	1.01
G.	Hot-water soak, alcohol wash, hot-water-laid	49.3	726	1.00

[a]Press dried at 149 °C, 3.0 MPa.
[b]Weighted fiber length determined by Kajaani FS-100.

from crumbs at 50% moisture content. The primary processes were (a) water-laid, hot rewet(as described in previous section), (b) air-laid, cold rewet (as described in previous section), and (c) alcohol-laid, cold rewet.

In the alcohol-laid process, the fiber furnish was dispersed in ethyl alcohol rather than water or air. The alcohol extracted water from the fiber, reducing its moisture content to near zero. Handsheets were formed in a sheet mold using alcohol as the fluid medium. After forming, the alcohol-saturated web was held for 48 hours in a humidity-controlled room at 90% relative humidity where the alcohol evaporated and the fibers regained moisture to approximately 18% moisture content. The web was then rewetted with cold water, wet pressed, and press dried in the manner of the air- and cold-water-laid webs. In this way, we were able to compare air-laid and liquid-laid webs made with dry fiber. To verify that no fines were lost in the forming process, a sample of each handsheet type was dissolved in water after forming and then analyzed in the Kajaani FS-100. The results show no significant variation in weighted average fiber length (Table 4).

A comparison of tensile index values for handsheets made from webs A and B (Table 4) shows the hot-water-laid web significantly outperformed the air-laid web. Comparing B to C, we note that performance was only slightly improved by alcohol laying of the dry fibers. The results indicate that the reduced performance of the air-laid webs was not simply a function of fiber placement or arrangement in the web but also involved the relative ability of the fiber to bond with other fibers in the network. Web types D through G verify that (1) bond potential of the air-laid fiber was not diminished by the alcohol wash (compare D with B), (2) a hot water soak to remove latency (residual twist and curl in the fiber) prior to forming was helpful even in air-laid webs (compare E with D), (3) a hot water soak was helpful for dry fibers, alcohol laid (compare F with C), and (4) the alcohol wash did not reduce the strength or bonding potential of hot-water-laid webs (compare G with A).

The failure of the alcohol-laid web C to perform significantly better than the air-laid web B leads us to infer that the performance of webs formed from dry fibers will not be greatly improved by further refinements in forming methods. That is, the challenge appears to lie with the fiber itself: its fibrillation, forming flexibility, and ability to re-establish strong bonds within the web. We see evidence of this challenge in Fig. 6. The air-laid web (a) shows almost no evidence of fiber fibrillation and bridging of bond sites—characteristics known to be associated with effective bonding and development of sheet strength.

Conclusions

Old newspaper (ONP) can be mechanically fiberized at moisture contents ranging from ovendry to >50% moisture content with a high yield of individual fibers. The potential for fiber damage (shortening of mean fiber length) is greatest at low moisture contents. At moisture contents from ovendry to approximately 20%, individual fibers can be disentangled from fiber flocks relatively easily and paper particles (nits) can likewise be separated from fibers. Disentanglement of fiber groups becomes significantly more difficult as moisture content increases above 20%. A variety of methods (machines) are potentially useful for fiberizing, but the fiber product is highly sensitive to operating parameters. We have not systematically optimized any of the methods we evaluated.

In our best effort to date, we fiberized ONP at 52% moisture content-retaining 97% of the fiber length in the control pulp obtained by the wet-disintegration in hot water. When wet-formed into 70 g/m^2 handsheets and press dried, this dry-fiberized pulp delivered 93% of the tear strength, 69% of the tensile

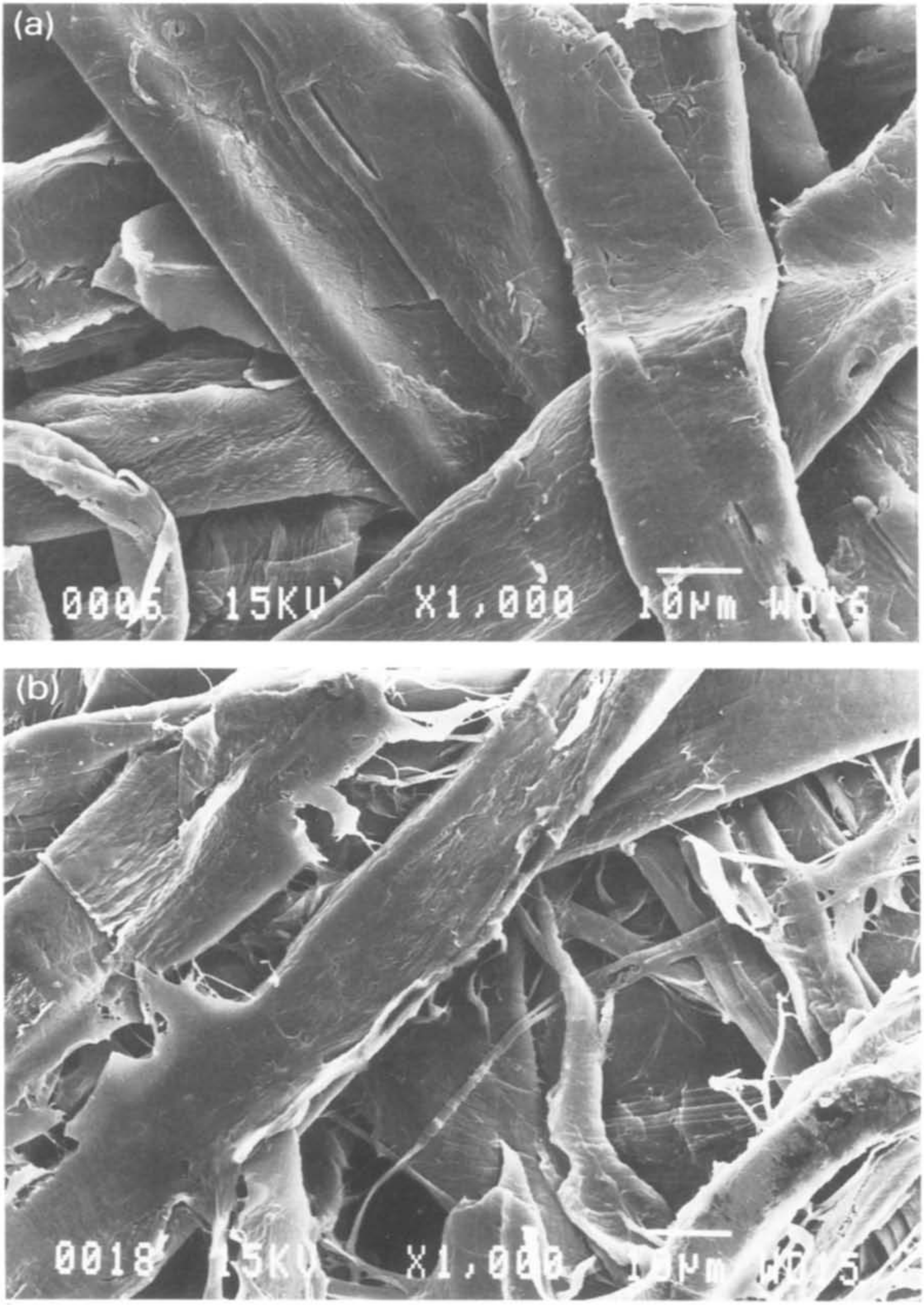

Fig. 6. (a) Scanning electron micrograph of air-laid handsheet (bar indicates 10 μm). Handsheet was formed from the same dry-fiberized furnish as handsheet shown in (b); differences in fibrillation and fibrillar bridging of bond sites are apparent. (b) Scanning electron micrograph of water-laid handsheet (bar indicates 10 μm). Handsheet was formed from the same dry-fiberized furnish as handsheet shown in (a); differences in fiber fibrillation and fibrillar bridging of bond sites are apparent.

strength, and 46% of the tensile energy absorption capability of the control pulp. Thus far, our best air-laid/press-dried method has produced handsheets with 91% of the density and 53% of the tensile strength of water-laid/press-dried handsheets made from the dry-processed fiber.

How then can the strength and toughness (tensile energy absorption) of air-laid handsheets made from mechanically fiberized pulp be improved? At least four possibilities are apparent:

(1) Optimize the mechanical fiberizing process to retain fiber length and enhance rebonding potential.
(2) Chemically modify the fiberized ONP to activate lost bonding potential.
(3) "Enrich" the ONP furnish with long fiber, either virgin or recycled, from higher grade products.
(4) Add "adhesive" to the air-laid fiber and/or to the rewetting water.

For the present, our experience with dry disintegration of ONP and air laying of newsprint-weight webs does not dispute the wisdom of over 100 years of development in papermaking. Wet-forming methods are hard to beat. Dry or semidry processing of newsprint will not come easily—and it may never be successful. However, if the demand for urban recycling of ONP is sufficiently strong, there is enough promise in our results to warrant further effort and exploration.

Acknowledgments

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