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VARIABLES IN PRESS DRYING PULPS FROM SWEETGUM AND RED OAK.(U)
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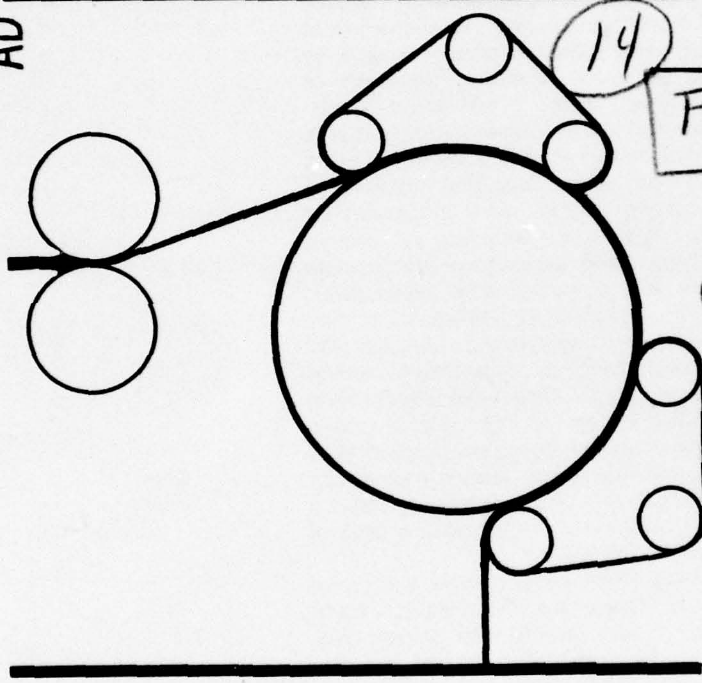

ABSTRACT

Press drying, a method to increase the utility of high-yield hardwood pulp for linerboard, overcomes fiber bonding deficiencies of conventional papermaking by controlling springback. During drying, press drying incorporated benefits both in plane restraint and thickness restraint. Use of heat and pressure during drying increased fiber conformability and plastic flow and offered some possible benefits of lignin bonding in addition to hydrogen bonding. Improvements in densification and bonding resulted in exceptional gains in edgewise compressive strength by utilizing the superior buckling strength of stiff, thick-walled fiber. Press-dried handsheets were much more dimensionally stable than conventionally dried sheets. In this investigation all fiber bonding-dependent properties--tensile, burst--were improved by press drying. With the exception of tearing resistance, high-yield sweetgum handsheets performed as well or better than press-dried handsheets from high-yield Douglas-fir; they were far superior to low-yield conventionally dried handsheets for burst, ring crush, tensile strength, and modulus of elasticity. Resistance to compressive creep of corrugated board from high-yield press-dried sweetgum was equal to or exceeded that of low-yield southern pine. Moisture sensitivity of adhesive, between liner and corrugating medium, was a critical factor influencing behavior.

Handsheets from blends with softwood fibers exhibited properties directly dependent on blend ratio. Little benefit was gained over pulp blending by combining hardwood and softwood pulp as laminations. In press drying, the moisture range, 39 to 20 percent, was most beneficial.

For continuous hot-press drying, webs were dried on a heated drum under pressures of a tight wire screen. The heavy press pressures prior to drying obviated the need for high pressure during drying. Final pressure for restraint did not have to be greater than 5 pounds per square inch.

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VARIABLES IN PRESS DRYING PULPS FROM SWEETGUM AND RED OAK

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INTRODUCTION

Today's fiber technology is remarkably versatile for producing fiber products that range widely in stiffness and strength. However, we are far from the ultimate of efficient utilization of the strength and stiffness that nature has built into wood fiber. Past success in creating new products has been based on the ability to understand, control, and modify *fiber flexibility; in doing so, interfiber bonding* can be controlled.

Most of the important differences in physical properties of papers made of pulps from various species and by various pulping processes can be accounted for by differences in fiber flexibility. Refining pulp to improve fiber surface as well as flexibility is so much a cornerstone of today's papermaking that to consider making paper without first refining pulp is considered "unthinkable" (5).[2]

The need to achieve acceptable levels of fiber flexibility severely limits use of thick-walled hardwood fibers for products in which strength and stiffness are governing factors determining product utility. Similarly the use of high-yield pulp (softwood or hardwood) is severely restricted by the increase in fiber stiffness and the loss in bonding that accompanies an increase in pulp yield.

Despite these difficulties in converting high-yield pulp fibers into paper, the decreasing availability and rising cost of raw materials have pushed industry inexorably toward higher yields. As a result, the present technology of papermaking is strained to its limits. *Is this not an opportune time, then, to consider* new methods for paper-making that will be less dependent on fiber flexibility.

One method to maximize fiber bonding with high-yield stiff fibers is by press drying, or Z-direction restraint, as described in an FPL Research Paper (7). The Paper describes *improvement* in properties of linerboard-weight handsheets from Douglas-fir kraft pulp cooked to a yield of 62 percent and dried under pressure to constrain springback in the thickness direction. It was shown that these special *drying conditions resulted in far superior prop*erties for handsheets from high-yield unrefined pulp than were obtained from well-beaten pulp in which handsheets were dried by the conventional, the standard TAPPI, method.

Lack of performance due to poor interfiber bonding is much more acute with thick-walled hardwood fibers than it is with the thinner walled softwood fibers. Thus the objective of the investigation reported here was to determine how hardwoods and hardwood-softwood mixtures responded to press drying. The data *from the earlier Paper (7) for Douglas-fir* were used for comparison with those of two hardwoods and hardwood-softwood mixtures.

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]Underlined numbers in parentheses refer to literature cited at end of this report.

EXPERIMENTAL

A series of kraft cooks of northern red oak (*Quercus rubra* L.) and sweetgum (*Liquidambar styraciflua* L.) were prepared for this investigation. Species, pulp yield, and freeness levels were selected to cover a broad range of potential fiber types and are given in the following tabulation:

Species	Pulp yield	Canadian Standard Freeness (CSF)				
	(Pct)	(Ml)				
Red Oak	67	245	355	455	530	690
	58	260	510			
	46	260	520	640		
Sweetgum	72	270	490	700		
	62	245	505	700		
	49	245	475	715		

Handsheets were made on a British sheet machine and had a basis weight of 205 grams per square meter or 42 pounds per 1,000 square feet (air dried). Some of the sheets were press dried and compared with similar sheets dried on disks and rings in accordance with the conventional procedure. Unless otherwise specified the hot press-dried sheets were dried under 400 pounds per square inch pressure with 400° F press platens for 30 seconds. Moisture was permitted to escape by placing the web between one 150-mesh metal screen on one side and five of the 150-mesh screens on the other. The multiple screens on one side were considered beneficial because they allowed moisture to escape as well as provided a cushion for more uniform pressure distribution.

Conventionally dried and press-dried handsheets were conditioned to 75° F and 50 percent relative humidity (RH) and evaluated to obtain edgewise compressive strength, tensile strength, modulus of elasticity, strain-to-failure in tension, burst strength, ring crush strength, MIT (Massachusetts Institute of Technology) folding endurance, and internal tear rsistance. Thickness and density values were obtained using Forest Products Laboratory apparatus for measuring effective thickness (6).

RESULTS

Press drying greatly enhances the prospects for increased use of hardwood in containerboard as well as increased yield from softwoods now used for corrugated boxes. Press drying is inherently more beneficial to hardwood utilization than to softwood because of the greater need to overcome bonding deficiencies caused by thick-walled hardwood fibers.

At every freeness level, all mechanical properties examined in this work were superior to those obtained by conventional drying except tearing strength. This property was improved only at high-freeness values. Especially noteworthy are the benefits to edgewise compressive strength and dimensional stability, or moisture-creep behavior, of press-dried paper. Although these benefits are important, other potential benefits are the following:

Effec[illegible]ilization of high-yield fibers

Red[illegible]r elimination of refining

Less [illegible]

Less water to remove on drying

Reduced forming costs through faster drainage

Reduced capital costs for stock preparation equipment

Most important--the potential for bonding stiff hardwood fibers now useful (if at all) only as fillers.

Compressive Strength

One of the most sought after properties in corrugated containers in recent years is top-to-bottom compressive strength. Although the fact that thick-walled, stiff hardwood fibers are most resistant to compressive buckling forces has been well understood (8), the lack of interfiber bonding and mutual support through densification has prevented using this fiber characteristic for increasing box strength.

Because of reduced interfiber bonding, conventionally dried hand-sheets of highest pulp yield exhibited the lowest edgewise compressive strength. However, in this investigation, the beneficial effects of added fiber bonding and densification due to press drying brought about a reversal of this trend so that the stiffer fiber always gave the highest edgewise compressive strength.

If samples of red oak and sweetgum handsheets are compared on an equal density basis, the influence of pulp yield is found relatively insignificant. Therefore, the comparison of edgewise compressive strength for sweetgum and red oak (fig. 1) does not show differences due to yield. These data show that press drying and conventional drying blend into one smooth, continuous curve for each species. At any of the densities, sweetgum sheets exhibit better compressive strength than do red oak sheets, and both are stronger than softwood sheets from Douglas-fir pulp (7). The data for the hardwood pulp include the full range of beating as specified and, since the data for Douglas-fir represent unbeaten pulp, the range of densities available for handsheets from the fir is necessarily smaller.

By correcting data for density differences, it can be shown that the gains observed are due to intrinsic structural improvements and more efficient fiber use rather than addition of fiber mass.

In considering these data, bear in mind edgewise compressive strength of commercial linerboard seldom exceeds 2,500 pounds per square inch in its strongest direction. Yet, with handsheets from press-dried hardwood pulp, this value can be exceeded two and one-half times. Thus, if sheet strength can be used as an indicator of box performance, it should be possible to make corrugated containers from hardwood species with at least twice the top-to-bottom strength of today's commercial boxes.

Because the compressive behavior of paper involves a buckling phenomenon and because the elastic modulus of the fiber is reflected by sheet modulus of elasticity, some relationship must exist between sheet modulus of elasticity and compressive strength of paper. These data for sweetgum pulp handsheets are plotted in figure 2. They are based on tests of conventionally dried and press-dried handsheets of beaten and unbeaten pulp from three yields (49, 62, and 72) levels. The data show an almost linear relationship between compressive strength and modulus of elasticity for each of the three pulp yields.

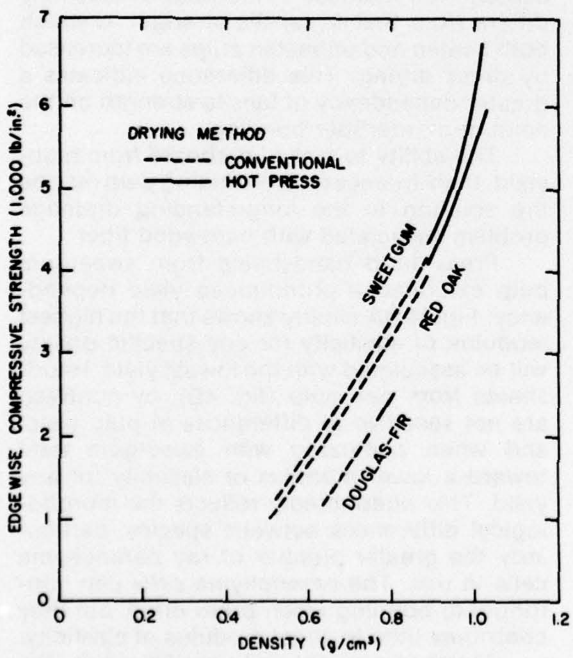

Figure 1.--Press drying increases edgewise compressive strength for handsheets for three pulps; hardwoods produce a stronger sheet than does softwood Douglas-fir.

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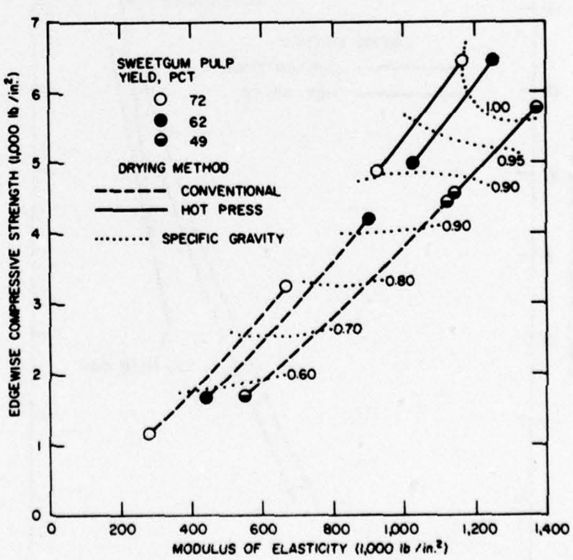

Figure 2.--Edgewise compressive strength (fiber buckling) depends on sheet (fiber) modulus and pulp yield. At constant sheet specific gravity, elastic modulus is reduced by increased pulp yield.

(M 145 149)

For a given modulus of elasticity the two highest pulp yields resulted in the greatest strength. This is to be expected because of the thicker cell wall and greater bending stiffness of high-yield pulp fiber than that of low yield. Lines of apparent equal specific gravity from 0.6 to 1.0 are superimposed on this graph. In general, although these data confirm the fairly constant relationship between specific gravity and strength, they also clearly demonstrate that under similar pressing and drying conditions it is possible by changing pulp yield to have a fairly wide distribution of elastic moduli for any given value of specific gravity. As pulp yield decreases, the elastic modulus increases, presumably because of the more favorable ratio of cellulose to lignin.

Tensile Strength

Tensile strength versus specific gravity curves for conventionally air-dried sheets do not coincide with those for press-dried sheets (fig. 3) as they did for modulus of elasticity versus compression (fig. 2). This very likely

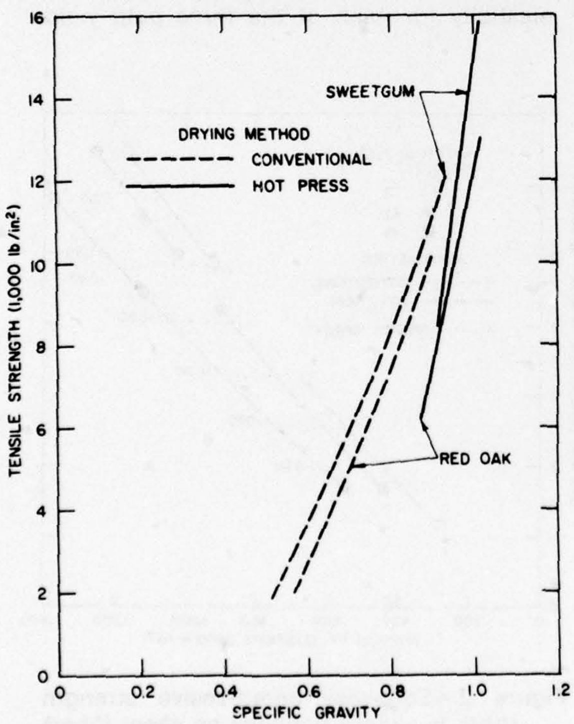

Figure 3.--Hot press drying increases tensile strength but not to the same extent as it does compressive strength (fig. 1).

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reflects a basic difference in mechanism of filure in the two testing modes. Sheet edgewise failure in the two testing modes. Sheet edgewise compressive failure results from bending of fiber segments, whereas tensile failures occur because of the breaking of interfiber bonds and fibers. Tensile failure is more dependent on fiber bond strength, whereas for compression beyond some optimum, it is less dependent. Press drying results in greater compaction of fibers in the Z-direction of the sheet at low beating levels, but unless potential bond strength is equal, conventionally air-dried sheets from well-beaten pulps will have higher tensile strength than press-dried sheets at the same specific gravity. Yield differences were not a significant factor influencing the relationship between specific gravity and tensile strength.

Modulus of Elasticity

Press drying will cause a substantial increase in modulus of elasticity (threefold increase) for beaten handsheets compared to that for unbeaten. This increase, however, diminishes with beating. There is, of course, less need for induced bonding if a pulp is well beaten. The increase in modulus of elasticity differs from that in tensile strength in which both beaten and unbeaten pulps are increased by press drying. This difference indicates a greater dependency of tensile strength on the amount of interfiber bonding.

The ability to make linerboard from high-yield, high-freeness, fast-draining pulp may be the solution to the long-standing drainage problem associated with hardwood fiber.

Press-dried handsheets from sweetgum pulp exhibited a pronounced yield dependency. Figure 4A clearly shows that the highest modulus of elasticity for any specific gravity will be associated with the lowest yield. Handsheets from oak pulp (fig. 4B), by contrast, are not sensitive to differences in pulp yield, and when compared with sweetgum tend toward a lower modulus of elasticity for any yield. This undoubtedly reflects the morphological differences between species, particularly the greater number of ray parenchyma cells in oak. The parenchyma cells can contribute to bonding when press dried, but they contribute little to sheet modulus of elasticity.

At the same yield and specific gravity the elastic modulus of handsheets of either sweetgum or red oak compared favorably with that of handsheets from high-yield (62 pct) Douglas-fir kraft pulp. Thus, for stiffness-dependent characteristics, the hardwood

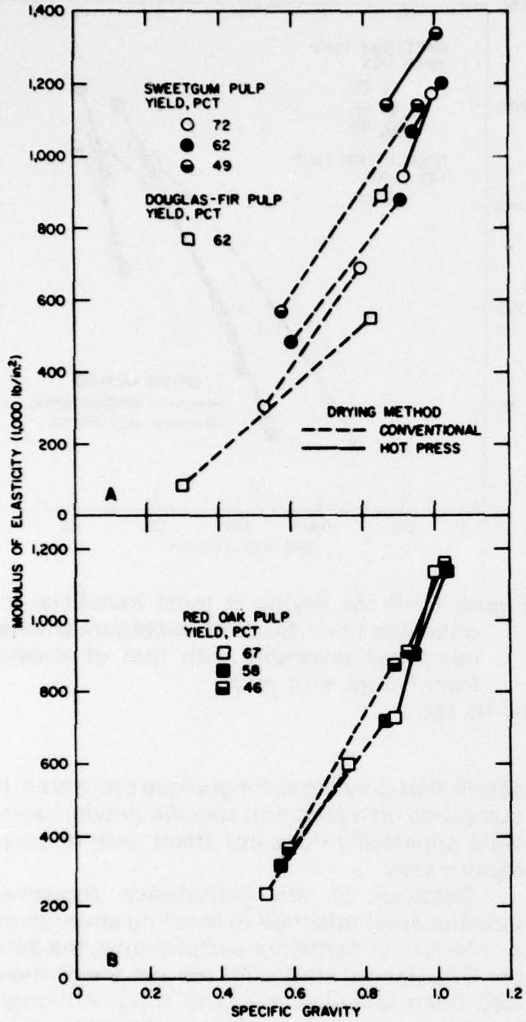

Figure 4A and B.--A, Press drying is more beneficial to unbeaten than to beaten pulp. Sweetgum handsheets can have elastic modulii comparable to or superior to those of softwoods. B, Modulus of elasticity of sheets from red oak apparently are not dependent on yield.

(M 145 151)

pulps are likely suitable substitutes for Douglas-fir pulp.

Strain-to-Failure in Tension

Strain-to-failure in tension usually increases with increase in specific gravity of conventionally dried handsheets because denser sheets usually indicate increased network bonding. This is also true of press-dried handsheets. Press drying compared with conventional air drying on the same specific gravity scale showed two distinctly different sets of data. For any value of specific gravity, conventional air drying increased deformation.

The handsheets from unbeaten pulps had greater stretch if press dried than those from beaten pulps. This, of course, results from greater fiber bending and extension prior to rupture. Handsheets from beaten pulps, by contrast, if press dried showed lower stretch due to a stiffer network and more intrafiber bonding incurred by the high drying temperature.

That restraint during drying in the x-y plane reduces extensibility of fibers is well known; thus network stretch is reduced. The data in figure 5A (sweetgum) and figure 5B (oak) represent, however, essentially the same amount of restraint during drying in the x-y plane. The existing differences are from temperature and Z-direction restraint during drying.

Low-yield pulps result in handsheets of low stretch if compared at the same specific gravity. If these pulp handsheets are press dried, the intermediate yield pulps (62 pct, sweetgum; 58 pct, red oak) resulted in handsheets with the greatest stretch. The ability to reduce fiber stretch by restraining during drying evidently has reached some restrictive limits (possibly bond dependent) for the thick-walled, high-yield fiber. Thus, there is a need for a more mechanistic explanation. This type of mechanism is expected to show that the fiber to fiber bond of press-dried sheets differs in quality from that of conventionally dried paper. This opinion is based on the difference in compressive creep behavior under cyclic humidity conditions.

Although fiber length has long been thought an important factor in determining strain-to-failure, apparently this is not necessarily fact. The strain-to-failure for press-dried handsheets from a well-beaten (350 ml CSF) Douglas-fir kraft pulp (62 pct yield) at our Laboratory was 3.2 percent. Comparable values for red oak were 3.6 percent and for sweetgum 3.1 percent. Thus, high-yield oak pulp if properly bonded may produce handsheets with greater stretch than those from a high-yield softwood pulp.

Bursting Strength

Burst values, reflecting as they do a large dependence on tensile strength and strain,

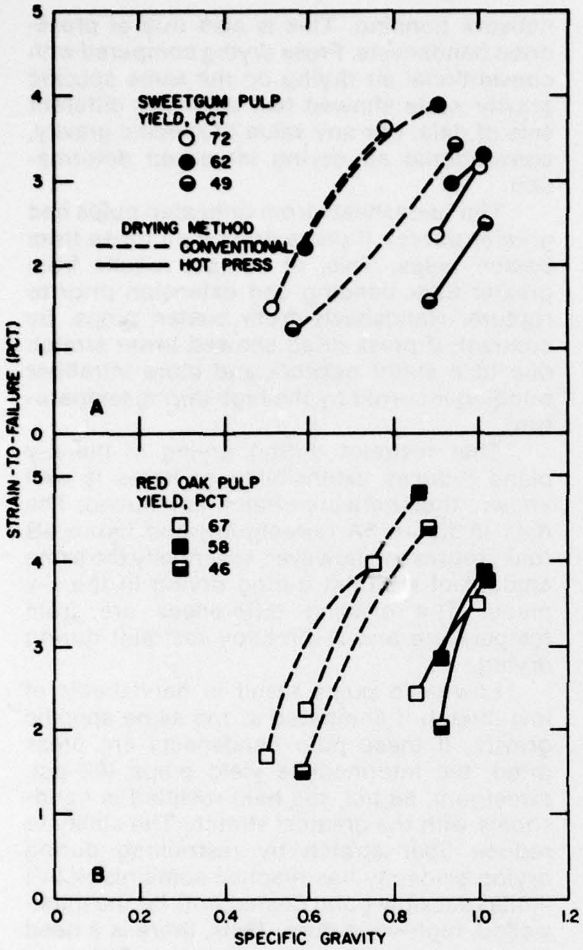

Figure 5A and B.--A, Press drying handsheets of sweetgum pulp increases strain-to-failure of unbeaten pulp handsheets by better bonding than does conventional, TAPPI standard, drying, but heat treatment results in a more rigid, less extensible sheet. Thus stretch of well-beaten pulp handsheets is reduced. B, Sheets of red oak pulp show stretch comparable or greater than do sheets from sweetgum pulp.
(M 145 152)

show a strong dependence on drying method. Curves of specific gravity versus burst, in figure 6, show that the increased densification from press drying adds little to the increase obtainable by beating and conventional drying, but press drying results in a considerable increase if pulp is unbeaten. The curves for the relationship of burst to specific gravity for sweetgum are so similar to those for oak hand-

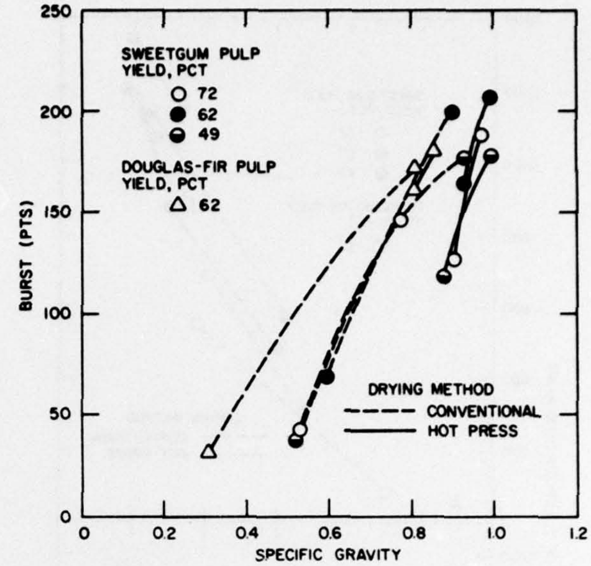

Figure 6.--Press drying is most beneficial to unbeaten fiber. Burst of sweetgum sheets compares favorably with that of sheets from Douglas-fir pulp.
(M 145 154)

sheets that only those for gum are presented. If compared on a common specific gravity basis, yield apparently does not affect level of burst significantly.

Because of the importance (however questionable) attached to bursting strength as a criterion for container performance, the data for Douglas-fir kraft pulp (62 pct yield) have also been included in figure 6 (7). Although burst values of softwoods for both press-dried and conventionally dried material show an increasingly favorable specific gravity to burst relationship, the magnitude of strength levels is not too different from that of hardwoods.

Ring Crush

Ring crush strength in this work apparently relates closely to edgewise compressive strength, but the actual stress level (about 2/3) is due to lower sheet bending of the unsupported edge of the specimen, whereas edgewise compression failures are due to fiber buckling well away from the edge of the sheet.

Folds

The folding endurance data (fig. 7A and 7B) on sheets from sweetgum and red oak fibers show the importance of fiber morphology. The finer, more flexible gum fibers in

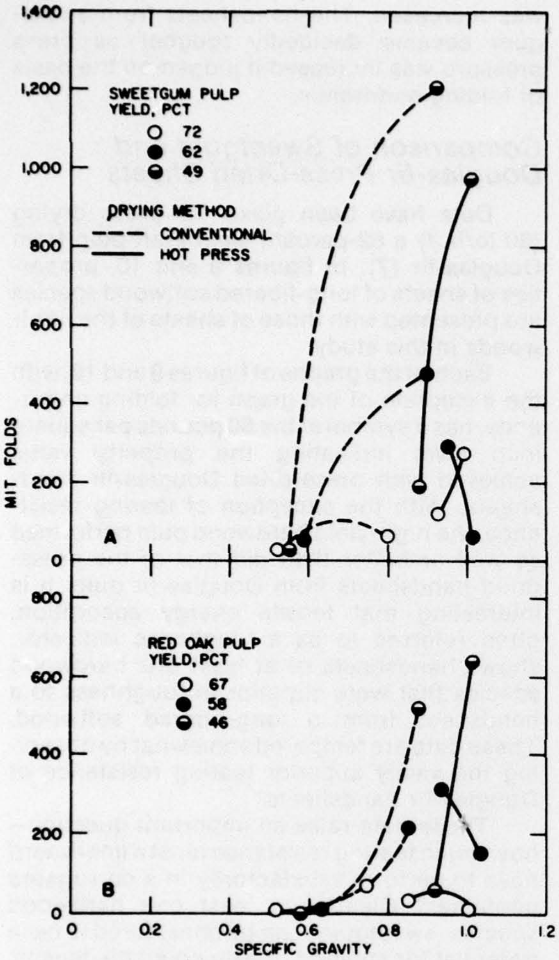

Figure 7A and B.--A, Low pulp yields for sweetgum handsheets are most beneficial to improved folding endurance; press drying does not generally improve this property. B, Note sheets from red oak have only half as much folding endurance as those from sweetgum. (MIT, Massachusetts Institute of Technology.)

(M 145 153)

handsheets provided better hinges and resulted in about twice the folding endurance of that of the oak fibers in handsheets. Yield has a pronounced influence. The lowest yields produced the highest number of folds. Press drying, by increasing the bonding density, was not beneficial to folding endurance.

Tear

The greatest deterrent to increased utilization of hardwoods is the inability of most paper from this fiber to meet the tearing resistance standards set for softwood species. Tearing resistance depends primarily on morphological factors, such as fiber length and cell wall thickness (2), and on number of fibers per gram. It is less dependent on interfiber bonding; thus press drying has little influence on internal tear resistance.

Press-dried handsheets of well-bonded, dense materials show about the same level or slightly poorer performance (fig. 8) than do conventionally dried handsheets.

The effect of pulp yield on tear (fig. 8) shows an inverse relationship. With either drying method, increased pulp yield reduced tearing resistance. This yield effect on tear probably manifests a change in number of fibers per gram over which the tearing force is distributed. This concept introduced by Sanyer (4) offers the most plausible explanation for the behavior of these pulps. Thus, even in well-bonded handsheets cell wall thickness or fiber strength apparently does not determine the level of tearing resistance.

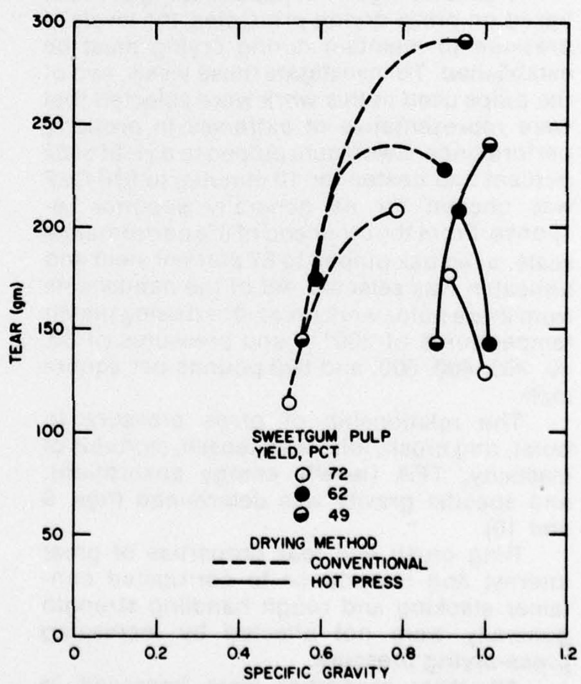

Figure 8.--Tearing resistance is dependent on fiber morphology; press drying tends to reduce maximum attainable tear.

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Dimensional Stability

Dimensional stability of handsheets on exposure to moisture was evaluated using sheets from high-yield (67 pct) red oak pulp. Humidification from 50 to 90 percent relative humidity of conventionally dried and press-dried sheets resulted in similar swelling behavior for press-dried sheets that were only half that of the conventionally dried sheets. This superior dimensional stability was also evident after a 2-hour water soak. Dimensional stability comparisons were also made between the high-yield (67 pct) press-dried handsheets from red oak pulp and low-yield (50 pct) machine-made sheets from softwood kraft pulp. Even with these extreme differences in yield and density, the press-dried sheets had less than half as much expansion on exposure to moisture.

The data indicate that the quality of bonding produced by press drying is distinctly different from that produced by conventional machine drying. Additional supportive evidence will be presented in a discussion of compressive creep behavior.

Pressure Series

In developing a new papermaking process based on press-drying principles, the levels of pressure to maintain during drying must be established. To investigate these levels, two of the pulps used in this work were selected that were representative of extremes in property performance. Sweetgum pulped to a yield of 62 percent and beaten for 10 minutes to 610 CSF was chosen for its generally superior response. From the other end of the performance scale, a red oak pulped to 67 percent yield and unbeaten was selected. All of the handsheets from these pulps were press-dried using platen temperatures of 300° F and pressures of 30, 60, 200, 400, 600, and 800 pounds per square inch.

The relationship of press pressure to burst, ring crush, fold, tear, tensile, modulus of elasticity, TEA (tensile energy absorption), and specific gravity was determined (figs. 9 and 10).

Ring crush and tear properties of great interest and importance to corrugated container stacking and rough handling strength generally were not affected by increasing press-drying pressure.

All other properties were improved in varying degrees by increased pressure during drying. With the exception of folding endurance, properties of both pulp types improved in parallel fashion as pressure during drying was increased. The handsheets from sweetgum became decidedly tougher as press pressure was increased if judged on the basis of folding endurance.

Comparison of Sweetgum and Douglas-fir Press-Dried Sheets

Data have been given for press drying (60 lb/in.[2]) a 62-percent yield kraft pulp from Douglas-fir (7). In figures 9 and 10, properties of sheets of long-fibered softwood species are presented with those of sheets of the hardwoods in this study.

Each of the graphs of figures 9 and 10, with the exception of the graph for folding endurance, has a symbol at the 60 pounds per square inch level indicating the property value achieved with press-dried Douglas-fir handsheets. With the exception of tearing resistance, the high-yield hardwood pulp performed as well or better than did that of the press-dried handsheets from Douglas-fir pulp. It is interesting that tensile energy absorption, often referred to as a toughness indicator, shows handsheets of at least one hardwood species that were superior in toughness to a handsheet from a long-fibered softwood. These data are tempered somewhat by observing the vastly superior tearing resistance of Douglas-fir handsheets.

These data raise an important question--how much tearing resistance must a linerboard have to perform satisfactorily in a corrugated container? Clearly, at least one hardwood species (sweetgum) can be considered to have potential for meeting or exceeding the tensile, the compressive, and the stiffness requirements of linerboard. However, until the minimum level of internal tearing resistance (or some other appropriate indicator) is established, the degree to which hardwoods will be used must be established on a case by case basis.

Comparison with Conventional Handsheets (Low-Yield)

Burst, ring crush, tensile, and modulus of elasticity graphs, figures 9 and 10, for press-dried materials also include the property level that may be expected of standard handsheets of conventionally dried low-yield kraft pulps. These data indicate the marked superiority of the press-dried sweetgum sheets. If edgewise compression or ring crush is the most desirable attribute in linerboard, then the most inferior pulp in this study (unrefined red oak kraft pulp with 67 pct yield) deserves to be considered.

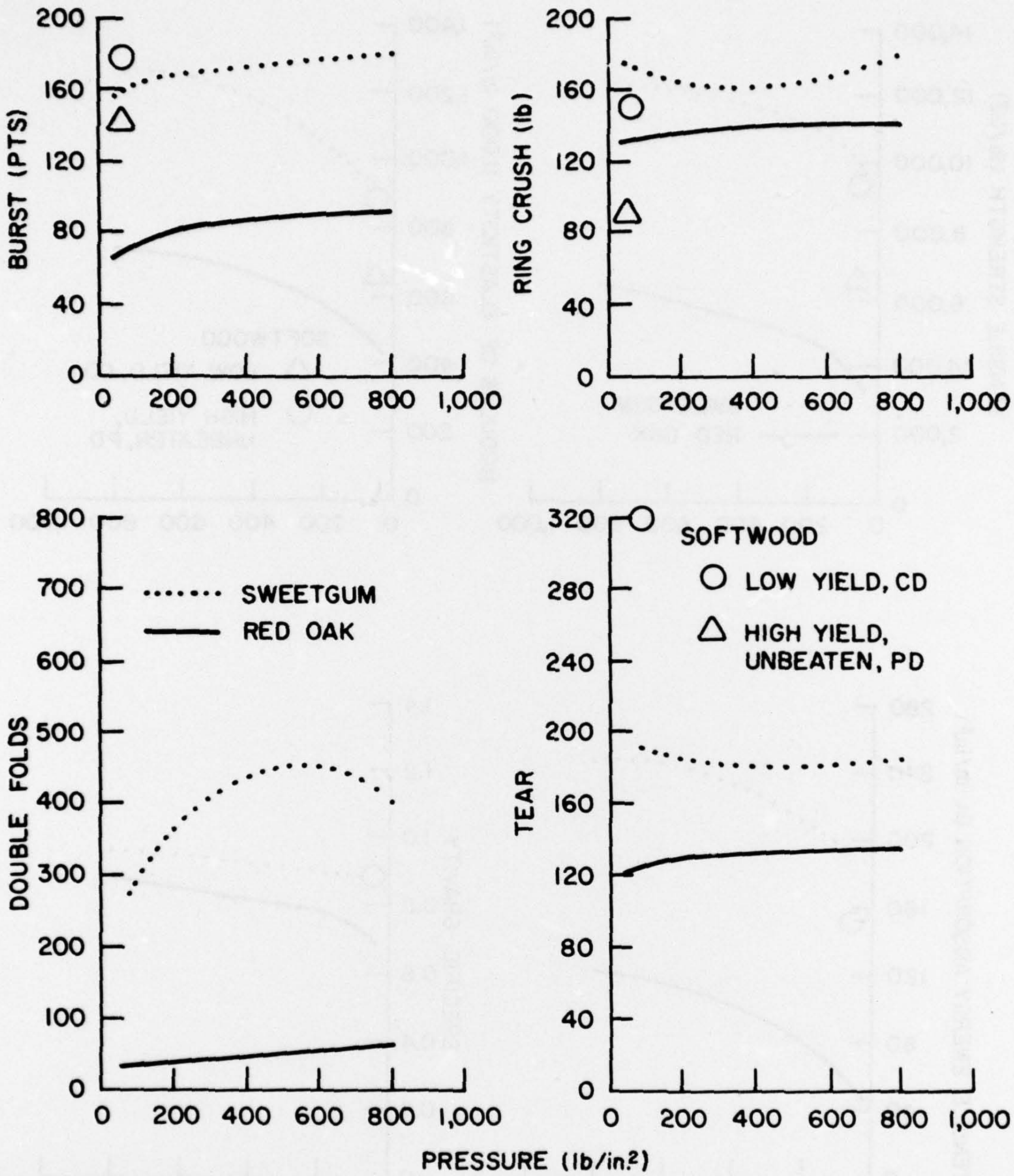

Figure 9.--Relationship of press pressure of handsheets to burst, crush, fold, and tear. Sheets of press-dried (PD) hardwood compare favorably with both conventionally dried (CD), TAPPI standard, and hot press-dried sheets of low-yield pulp softwood. (Sweetgum, 62 pct pulp yield, 610 CSF; red oak, 67 pct pulp yield.)

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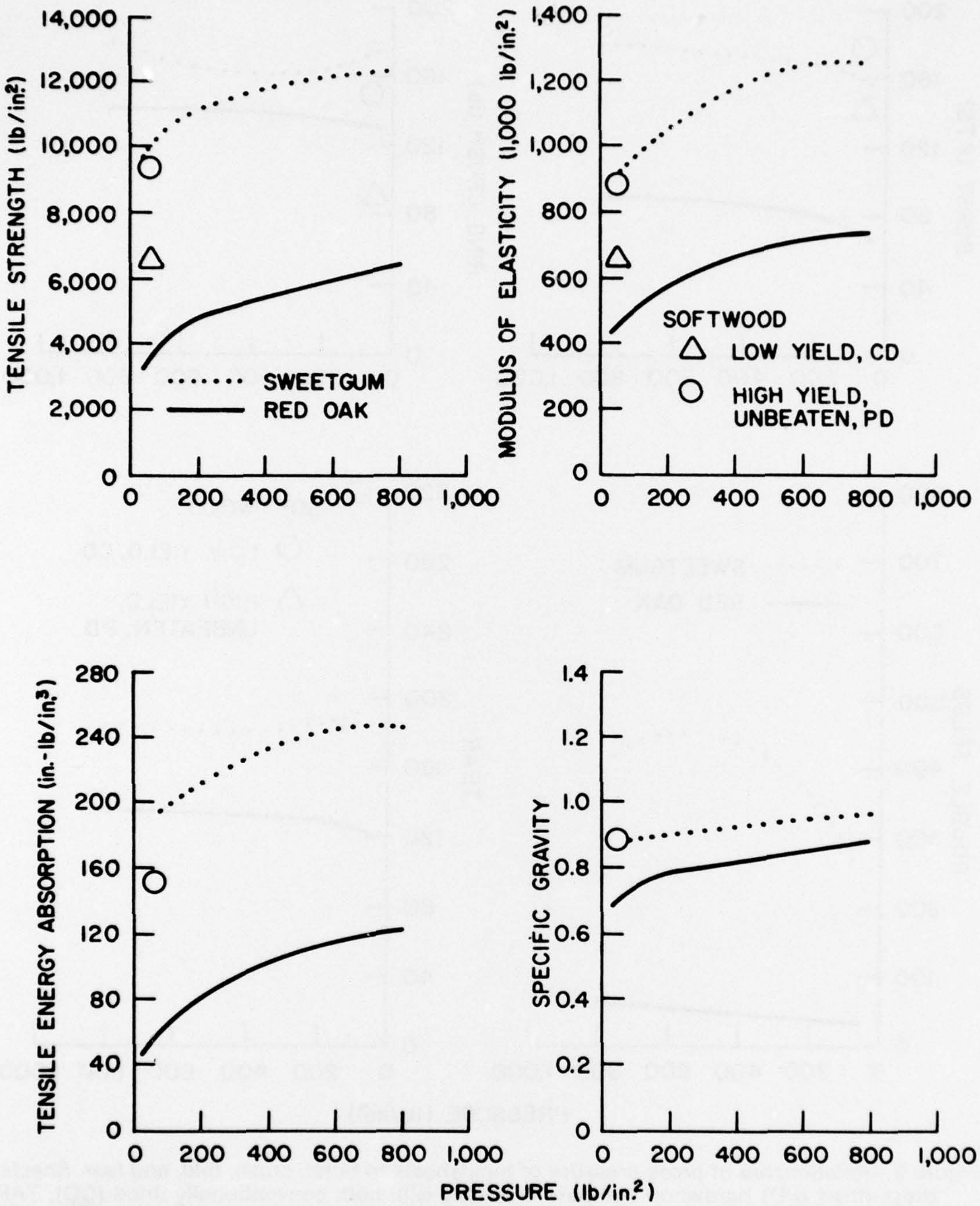

Figure 10.--Relationship of press pressure of handsheets to tensile strength, modulus of elasticity, tensile energy absorption, and specific gravity. Sheets of press-dried (PD) hardwood compare favorably with those of conventionally dried (CD), TAPPI standard, and press-dried low- and high-yield softwood sheets. (Sweetgum, 62 pct pulp yield, 610 CSF; red oak, 67 pct pulp yield.)

(M 145 157)

Temperature-Drying Rate

The effect of temperature on drying rate, like other aspects of this research, should have more emphasis than was possible in this investigation. However, it is in order to describe experiments of drying rate as they relate to this study, although the identical drying condition may never be reproduced elsewhere.

Although the experiments on drying rates were on handsheets from beaten and unbeaten softwood pulps, it is assumed that substituting hardwood for the softwood species would not greatly alter results.

During press-drying, a 205-gram sheet was sandwiched between five screens of 150-mesh and a 150-mesh single screen. The platen pressure was held at 60 pounds per square inch. During drying, the platen pressure had to be maintained as water was displaced. Sheet dryness was indicated by the absence of a drop in pressure. At this point (no tendency to pressure drop), the sheet was left an additional 10 to 15 seconds to insure complete dryness. The initial moisture content was about 70 percent (based on the total wet weight of the sheet).

A curve for drying time versus temperature up to 500° F is shown in figure 11. Total drying time at 200° F was about 15 minutes, whereas at 500° F the sheet dried in about 5 seconds. Moisture moved easily from the surface of the web through the press screens; however, it was somewhat restricted because it had to move laterally through the screen to be removed from the press. Thus, it is difficult to use data in figure 11 to estimate drying rate under another set of continuous pressing conditions.

The properties of handsheets at these temperatures tended to be relatively unaffected by temperature; the largest change (13 pct reduction at 500° F) was in folding endurance.

Hardwood-Softwood Mixtures

Property deficiencies of any pulp can be improved by blending with pulp that has desired characteristics. This approach, like beating or refining, requires judicious balancing. A series of experiments blending softwood pulp with hardwood pulp was conducted at the Forest Products Laboratory in which the principal tradeoff involved reduced hardwood edgewise compression or ring crush strength and increased softwood tearing resistance.

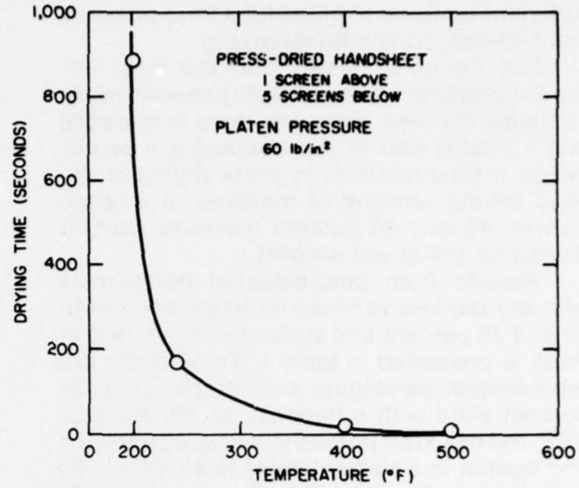

Figure 11.--Relationship of drying time of press-dried handsheets to temperature.
(M 145 159)

Although the extensive results will not be covered in depth in this report, two useful findings can be generalized:

1) *Strength, specific gravity, and stiffness* of press-dried blends will usually exhibit a *linear relationship* with the hardwood-softwood ratio of the pulp blend.

2) *Density, tensile strength, modulus of* elasticity, strain-to-failure, burst, ring crush, fold, and tear of press-dried sheets of hardwood-softwood pulp blends in a 50:50 ratio will be about the same as laminates in sandwich form from the same hardwood-softwood pulp ratio. Although some deviations to this generalization were noted, none of the results was sufficiently different to justify a proposal for laminating hardwood-softwood pulp sheets to improve the properties examined in this study.

Critical Moisture Range

The future utility of press-drying concepts depends largely on the economic practicality of sufficiently high drying rates. The problems associated with holding a wet web in a totally restrained condition while maintaining high production rates is yet to be solved. A concept that can ease the problem is press drying only in the critical moisture range. This is a three-phase concept that suggests conventional pressing and drying to some predetermined moisture level followed by a second phase of press drying and release of pressure after sufficient bonding to allow for a third phase of more-or-less conventional drying.

Experience indicates that the most improved bonding will result from press drying to complete dryness. However, there is evidence that a sizable part of this bonding will be obtained if total restraint in press drying is applied during removal of moisture in a range betwen 40 and 20 percent moisture content (based on initial wet weight).

Results from cold-pressing handsheets with dry blotters to lower moisture content to 39 and 35 percent and subsequently drying in rings is presented in table 1. Three pulps are represented: Sweetgum kraft pulped to a 72-percent yield with a freeness of 700 milliliter CSF; red oak kraft pulped to a 67-percent yield and beaten in a Valley beater to a CSF of 580 milliliters; and a red oak kraft pulp with a 58-percent yield beaten to 510 milliliter CSF.

The sheets were cold-pressed at 800 pounds per square inch for 5 minutes with a standard TAPPI disk on one side, a 150-mesh nylon screen on the other, and six dry blotters next to the screen. After the sheets reached 39 or 35 percent moisture content, they were removed from the press and placed in a 200° F oven with standard drying rings separating the pressed sheets still on the drying disks. Sheets were also dried by the hot press method under pressures of 60 or 800 pounds per square inch.

The data in table 1 show that the benefits of first removing water by cold-pressing will depend on fiber type. The longer, stiffer, high-yield (72 pct) sweetgum fibers exhibited considerably more springback and bonding loss than did the lower yield red oak pulp beaten to 510 milliliter CSF when compared with hot press sheets of comparable specific gravity.

Tensile properties and ring crush strength were the most sensitive indicators of losses from springback. Examination of table 1, using these properties as guides, suggests that even fairly high-yield, inflexible fibers can be cold-pressed to 40 percent moisture content and if dried under x-y restraint after pressing will give good sheet properties. Under these conditions, strengths will be about 70 percent of what they might have been if only subjected to hot press drying. Even higher ratios of strengths can be obtained by resorting to additional pulp refining or selecting a pulp of lower

Table 1.--Comparison of properties of cold- and hot- press-dried handsheets from three pulps[1]

Handsheet property	Cold-[2] (C) and hot- (H) press-dried							
	Sweetgum, 72 percent yield (700 CSF)		Red oak, 67 percent yield (580 CSF)			Red oak, 58 percent yield (510 CSF)		
	C	H	C	H		C	H	
	66-39 percent MC	800 lb/in.^{2}	66-35 percent MC	800 lb/in.^{2}	60 lb/in.^{2}	71-39 percent MC	800 lb/in.^{2}	60 lb/in.^{2}
Basis weight (g/m^2)	199	211	213	211	203	197	196	207
Specific gravity	.88	.93	.92	.95	.78	.98	.97	.87
Burst (pt)	91	123	107	133	102	140	154	144
Ring crush (lb)	126	188	146	164	150	147	143	164
Folds (no.)	107	125	100	77	53	355	301	173
Tear (g)	158	154	152	153	148	166	156	171
Tensile strength (lb/in.^{2})	6,570	9,510	6,960	9,420	6,080	9,500	10,800	8,510
Modulus of elasticity (1,000 lb/in.^{2})	735	1,140	743	919	671	846	1,020	851
Strain-to-failure	2.66	2.60	3.61	3.40	2.71	4.15	3.90	3.64

[1]MC, moisture content.
[2]Final drying in restraining rings.

yield.

On the other end of the drying process (20 pct to 0 pct moisture content), apparently the range where Z-restraint is necessary can be reduced; tensile strength data for sheets taken out of the hot press, then dried finally in drying rings are shown in figure 12. (The authors think that under these conditions the final stage of drying was essentially one in which the sheet was virtually unrestrained because of lack of adhesion to the disk.) These data (fig. 12) represent handsheets from unrefined Douglas-fir kraft pulp with a 62-percent pulp yield. Thus, for this pulp apparently little strength will be lost if the press-dry process is terminated at 20 percent moisture content.

On the basis of what is known about effects of restraint during drying, a suggestion to increase toughness (at the expense of sheet stiffness) is to allow additional unrestrained drying at the end of the drying process.

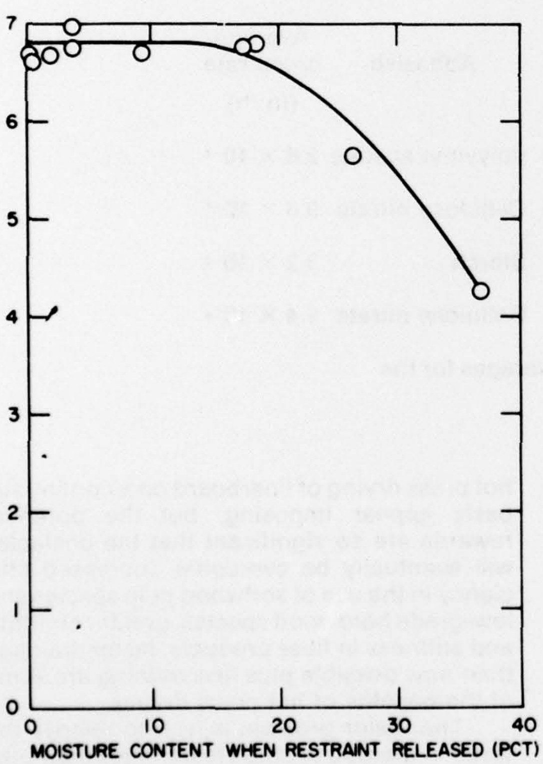

Figure 12.--Tensile strength losses occur when moisture content exceeds 18 to 20 percent (when press pressure is released).

(M 145 158)

On the basis of the observations here, apparently there is good reason to expect that the benefits of press drying can be secured without removing all moisture. By limiting press drying to the range between 40 and 20 percent moisture content, worthwhile gains in strength and stiffness will be obtained.

Lignin Bonding

A question that arises when high-yield pulps are pressed at high temperatures and pressures is--are lignin bonds formed during drying? Then the question follows--are the improved properties associated with high-yield pulp and press-dried sheets due to added lignin bonding or are they attributed to improved conformability of fibers?

In an attempt to find answers, press-dried handsheets were made at 400° F and at 70° F. A series of press pressures was used to establish a match in specific gravity for handsheets dried under the two temperatures. The assumption, of course, was that at 400° F the wet sample would incur lignin flow and bonding, whereas at 70° F it would not.

A corresponding specific gravity of 0.84 was achieved at 60 pounds per square inch for the heated press-dried sample and at 400 pounds per square inch for the unheated press-dried sample. The tensile loading at failure of the hot press-dried sample was 19.0 kilograms; the cold press-dried sample, 14.2 kilograms. Thus, the hot press-dried sample apparently possessed superior fiber bonding either from greater conformability or from added lignin bonding. After a water soak for several hours, the tensile strength of the hot press-dried sample was reduced from 19.0 kilograms to 0.62 kilogram; the cold press-dried sample, to 0.15 kilogram.

On the basis of tests of the water-soaked material, it may be assumed that the absolute level of lignin bonding could not be high and that the greatest effect of heating is to increase the plasticity of pulp fiber, which results in improved bonding and tensile load-carrying capacity.

These data can be interpreted differently if it is assumed lignin bonds will dissociate in water or if it can be shown that the absolute level of lignin available is too low to achieve appreciable lignin bonding under any condition.

The possibility of superior lignin bonding within a fiber wall is supported by reduced swelling of the hot press-dried sheet after soaking in water. The hot press-dried sheet swelled in thickness from 9.8 mils to 19.0 mils, whereas the cold press-dried sheet swelled from 9.8 mils to 29.0 mils when soaked in water.

Examination of the wet-to-dry tensile strength ratio shows the hot press-dried ratio to be 0.033 or three times greater than the cold press-dried ratio of 0.011. Thus, if the absolute amount of lignin on the surface of fibers is low, it may be argued that what small amount is available easily forms interfiber lignin bonds.

Creep under Compression Loading

Earlier evidence (dimensional stability and lignin bonding) indicated a possibly unique character of hot press-dried paper. Because creep properties of paper are known to be highly dependent on the interfiber bond quality of paper, an additional investigation was conducted on creep rate under edgewise compression loading.

In compression tests of handmade, corrugated board with facings of press-dried sheets, the samples were subjected to 3-1/2-hour cycles of relative humidities (RH) between 87 and 35 percent RH. The compression samples were subjected to a dead load equal to 40 percent of the average compressive strength at 87 percent RH. Compressive deformations were monitored continuously over a 1/2-inch gage length for the 1-inch-high samples (flutes parallel to direction of load).

The press-dried material for testing was obtained from unbeaten sweetgum pulp with a 72-percent yield. The adhesive for bonding corrugating media to liners was cellulose nitrate (nonwater soluble) in one sample and polyvinyl acetate (water soluble) in another. Samples of machine-made corrugated board of southern pine kraft pulp with a 55-percent yield were included for comparative purposes. One sample was bonded with starch and the other with cellulose nitrate to match the adhesive of the press-dried material. The results of these tests are shown in the following tabulation:

Material and Yield	Adhesive	Average creep rate (In./h)
Hot-pressed sweetgum (72 pct)	polyvinyl acetate	2.6×10^{-4}
Hot-pressed sweetgum (72 pct)	Cellulose nitrate	0.6×10^{-4}
Southern pine (55 pct)	Starch	3.2×10^{-4}
Southern pine (55 pct)	Cellulose nitrate	1.4×10^{-4}

(Creep rates are approximate averages for the total test-to-failure.)

From the data it can be concluded that the creep rate for hot press-dried, high-yield hardwood pulp samples is no greater than that for conventionally dried samples from low-yield (55 pct) southern pine pulp. Obvious, also, is the fact that the quality of the adhesive used to bond the linerboard and the corrugating media has a profound influence on creep rate induced by cyclic relative humidity. Moisture sensitive adhesives like polyvinyl acetate and starch will inhibit compression creep in linerboard to a lesser extent than will the more water-resistant butyl acetate.

Continuous Hot Press Drying

The obstacles to effective and economical hot press drying of linerboard on a continuous basis appear imposing, but the potential rewards are so significant that the obstacles will eventually be overcome. Increased efficiency in the use of softwood pulp species and low-grade hardwood species, greater strength and stiffness in fiber products, faster drainage than now possible plus less refining are some of the benefits of hot press drying.

The major problem is how to remove the water in the web at much faster rates than conventional drying now allows and maintain continuous pressure until the sheet is dry or at least through the critical drying range (40 to 20 pct moisture content).

A relatively simple continous press (12-in. diameter, 250° F) was constructed to demonstrate that properties similar to those achieved with flat presses were possible to achieve.

This roll press was equipped with a discarded bronze 75-mesh Fourdrinier wire with a 25-inch wrap on the drum. Although pressure exerted on the hot roll is not known exactly, on the basis of calculations from wire deflection measurements, the wire tension forces were estimated to be probably no greater than 25 pounds per lineal inch and the normal pressure on the roll at the point of highest pressure, about 5 pounds per square inch.

With this device linerboard could be dried on a continuous basis, and the board had about 80 to 90 percent of the strength and stiffness achieved under flat-press pressure of 60 pounds per square inch at 300° to 400° F.

This was possible by cold-pressing (dewatering and compressing) the sheet immediately before press-drying. Evidently wet high-yield fibers can be compressed to an extent that obviates the need for higher wire tension. Although this type of pre-pressing (estimated at 200 $lb/in.^2$) may produce severe crushing with low-yield, well-beaten furnish, it apparently does not cause any difficulty with the high-yield unrefined pulp.

The discovery that high press-drying pressures are not essential and that there is a critical moisture range for press drying brings the possibility for successful design of continuous press drying of paper much nearer to realization.

To maximize the resident time of the wet web on the press roll, the diameter of the roll must be as large as possible. There is a limit to diameter, however, because to increase the diameter and maintain constant wire pressure, tensile strength of the wire must increase in proportion to diameter increases. As an example, a stress limit of 60 percent of yield strength is chosen for 70-mesh wires of phosphor bronze (75,000 $lb/in.^2$) and high-strength stainless steel (200,000 $lb/in.^2$), the maximum tensile load will be 121.2 and 323 pounds per inch for bronze and stainles steel, respectively (assuming a filament diameter of 0.007 in.).

Assuming that a pressure of 5 pounds per square inch is to be maintained on the web and that the wrap around the cylinder will be 180° F, these wires will allow roll diameters up to 8 feet (phosphor bronze) and 21.5 feet (stainless steel).

The amount of water to be removed from a 42-pound linerboard web for reducing moisture content from 39 to 20 percent is 0.00985 pound per square foot. If the drying capacity of 15.71 pounds per hour times square feet (1) is maintained, the web will be required to remain under pressure for 0.0376 minute. Thus, the maximum roll speed for the 8-foot diameter roll with a 70-mesh phosphor bronze wire will be 8 divided by 0.0376 or 215 feet per minute, and the maximum speed for the 21-1/2-foot diameter roll with a 70-mesh stainless steel wire will be 573 feet per minute.

Because these values do not approach normal running speeds for drying linerboard at 1,600 to 2,200 feet per minute, it is suggested that additional efforts to increase drying capacity be required. There are a number of possibilities. One simple method that would entail some sacrifice of physical properties would be to utilize several press dryers in a stepwise pressing operation. This possibility was foreseen and examined in an earlier report (7).

A far more interesting possibility would utilize the fact that press-dried paper from unrefined high-yield fibers is at least three to four times more porous than conventionally dried paper. Research by Rohrer and Gardner (3) suggests that "through drying" rates of 60 to 100 pounds per hour times square feet are possible with light paper grades. If a uniform air pressure is applied to the web in combination with the press wire, the increased average pressure probably will allow for some reduction in the already high wire tension.

Another possibility would be to construct specially designed high-tension wires to allow for larger roll diameter.

Of these possibilities, the best solution may be a combination of press drying and conventional drying.

Additional Observations

During this investigation, additional observations were made. Although press-dried handsheets in this study have a higher specific gravity than most conventionally dried linerboard weight sheets, they are much more porous. The specific gravity values will seem higher, too, because they are based on effective thickness. For an estimate of specific gravity based on thickness determined by the TAPPI method, subtract 0.10 from the reported value.

If the reader tends to arbitrarily reject considering high specific gravity sheets, it should be remembered that press-dried sheets do not behave like conventionally dried sheets. The authors think that high specific gravity *per se* is of little significance if all other performance criteria are acceptable.

Press-dried material has flatter surfaces than has conventionally dried paper. Areas of high-basis weight will be compacted to the same thickness as low-basis weight areas of a sheet. A sheet in which flatness is improved should also improve converting operations that involve printing or gluing.

In today's conventional papermaking, energy is wasted and pulp fibers are damaged by beating, and refining is considered necessary. Press-dried sheets require little or no beating to achieve high levels of strength.

FINAL COMMENT

Based on the findings in the investigations reported here, press drying offers a great potential for increasing the utilization of low-grade species; for justifying increases in the yield of softwood pulp; and for producing stiffer, stronger fiberboard boxes than are now available.

The most urgent need for future research is to increase drying rate with an ultimate goal of one-step complete drying.

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Variables in press drying pulps from red oak and sweetgum, by Vance C. Setterholm and Roy E. Benson, Madison, Wis., FPL 1977.
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Handsheets of two hardwoods and hardwood-softwood mixtures are analyzed for their performance after press drying.

KEYWORDS: Press drying, red oak, sweetgum, restraint, fiber bonding, compression, dimensional stability, burst, ring crush, high-yield pulp, low-yield pulp.

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