**Preferred citation:** E.L. Back. The present state of press-drying of paper. Part 1: The fundamentals of press-drying. In **The role of fundamental research in paper-making**, *Trans. of the VIIth Fund. Res. Symp. Cambridge, 1981*, (Fundamental Research Committee, ed.), pp 343–364, FRC, Manchester, 2018. DOI: 10.15376/frc.1981.1.343.

# THE PRESENT STATE OF PRESS-DRYING OF PAPER

Part 1
by Ernst L. Back,
Swedish Forest Products Research Laboratory,
Stockholm, Sweden

Part 2
by Roy Swenson,
Manager, Mechanical Developments,
International Paper Research,
Tuxedo Park, N.Y.

**Abstract**

In the first part of this paper (by E. Back) the fundamentals of press-drying are reviewed. Effects of process variables in single stage press-drying promoting the flow of wood components (especially lignin) under heat, moisture and pressure are illustrated. For press-drying of hardwood pulps the role of residual lignin in parenchyma cells, with delayed removal in pulping, is analysed. The possibilities of short, multiple-stage press nips as useful for continuous paper production are exemplified.

In the second part (by R. Swenson) the application of the press-drying process is discussed for different paper grades. Various pilot plant approaches to dynamic, i.e. continuous, press drying are shown. The variables which affect the product and process are presented, with the results obtained when going from static press-drying to a dynamic slow speed press-drying machine. The problems of high speed press-drying are projected and discussed and the application of press-drying to a paper machine is shown.

## Part 1

# THE FUNDAMENTALS OF PRESS-DRYING

### Definition and significance

Sheet density is the main factor governing the strength properties of paper, because of its dominating effect on the bonding area and free fibre segments. In standard paper-making high sheet density is achievable

* by refining, which increases both the capillary forces for auto-contraction during drying and the compliability of the fibres to these forces;

* by delignification, making wood fibres more compliable to these capillary forces at normal drying temperatures;

* by additional wet pressing, up to breaker stack positions.

Press-drying is another way of enhancing sheet density. It is a process where drying takes place under external pressure perpendicular to the sheet, while simultaneously applying heat to at least one of the sheet sides in order to raise the drying temperature above that of normal cylinder drying, whereby the fibrous material becomes more compliable.

At normal drying temperatures i.e. usually 60 to 70°C in the web, hemicellulose and amorphous cellulose are sufficiently above their glass transition temperatures to flow even in response to rather low forces, such as those existing in auto-contraction. However, two fibre components do not flow under these conditions and thus counteract the overall flow of the material. These are the crystalline cellulose, with its melting point of about 400°C, and the lignin with its glass transition in the moist state of about 115°C when native, and down to 90° to 70°C when partially sulphonated or oxidised. Therefore, press-drying is most useful for bonding high lignin pulps as well as some low hemicellulose, highly crystalline cellulose pulps. Also, it is especially useful where conventional refining is not suitable or not easily accomplished.

Optimum flow requires a temperature of 60° to 80°C above the glass transition temperature, which fact has to be considered in respect to the pulp components and their moisture content. Press-drying or, ultimately, hot pressing is also then useful for bonding fibres without binders under water-deficient conditions, provided temperatures sufficiently above the glass transition temperatures of the dry pulp components are used.

Single stage press-drying allows the possibility of producing nearly standard kraft-strength properties even from thermomechanical pulps, from shives and even from rejects containing only fibre bundles, but at higher sheet densities. It can be said to have been invented in 1925 by William Mason(1), who produced from coarse thermo-mechanical fibre bundles a hardboard with the strength properties of kraft papers but at a density of about 1000 $kg/m^3$. Since 1926, single stage press-drying has been in commercial production for heavy basis weight building boards produced at low speeds and depending mainly on hydrogen bonding. Research on the application to paper manufacture started independently and about simultaneously in 1973 in the US(2) and Sweden(3).

This paper will deal first with the principles of press-drying for paper manufacture, then with its present state in respect to machinery and paper products. The potentials of this process for using hardwoods and high yield pulps are especially elaborated.

## Principal process variables

The principal internal parameters for bonding in press-drying are the temperature and pressure in the fibrous web as a function of the drying time and web moisture content. These parameters then are relevant in relation to the moisture-dependent flow properties of the fibrous material and its components. The external operational parameters then are the pressure applied, the temperature of the press platens, and the way of letting the water escape from the nip e.g. the screen mesh. In principle, each of these parameters can be varied over the press-drying period, with the solids content at which the single stage nip or each of the various multiple stage nips is started and ended.

If press-drying of a wide web takes place between two hot platens or between a cylinder and a heated metal band with one or two wires in between to permit the water and water vapour to escape from the nip, then most of the evaporation takes place at a temperature at which the vapour pressure is near or less than the mechanical platen pressure applied. The total applied pressure, $P_T$, just as in wet pressing, is taken up as a network pressure $P_N$ and a hydraulic pressure $P_H$. This hydraulic pressure during evaporation is equal to the saturated vapour pressure at the drying temperature in the web. In single nip press-drying it can stay rather constant over a large part of the drying period, as exemplified in figure 1. It is determined by the flow restrictions for evaporated vapour and by the evaporation rate and thus by e.g. the screen mesh, and by press or web dimensions. These flow restrictions are valid maybe up to a dry content of 85%. Thereafter the temperature in the paper rises during final drying up to that of the press platens.

Since the flow between the hot platens is parallel to the sheet over a long distance through a fine wire, the press nip during the main drying period is often flow limited. Thus if the platen temperature is higher than corresponds to the applied pressure, the temperature and vapour pressure $P_H$ follow the applied total pressure during evaporation. If the press platen temperature is much lower than corresponds to the applied external pressure the temperature in the web can rather rapidly rise to nearly this temperature and evaporation takes place at it. In the former case then, the applied external pressure determines the evaporation temperature: in the latter case the press platen temperature determines the evaporation temperature.

Thus, the external pressure applied in such a nip is useful both to determine the evaporation temperature, and thereby the flow resistance of the fibrous material during drying, and at

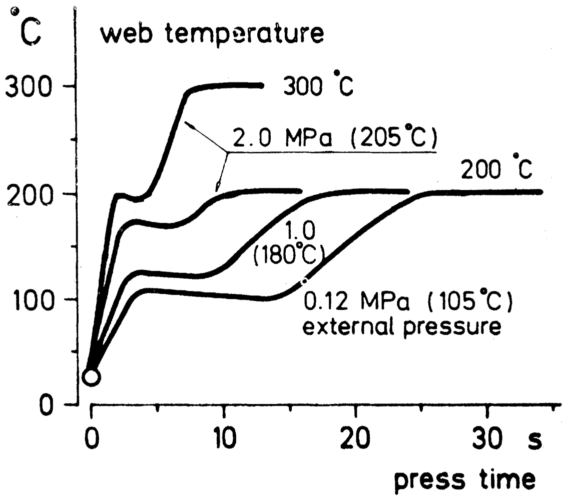


**Fig 1**—The temperature in the centre layer of the web *vs.* time in single nip press-drying using 200° C and 300° C platen temperature. Also noted for each curve is the external pressure applied and a corresponding maximum evaporation temperature during the main drying period.

this temperature to promote the flow of the fibrous material. Also, the water in the nip reaches this temperature above 100°C and a corresponding pressure. Because of the corresponding low water viscosity, dewatering before evaporation can be rather efficient. On the other hand, there must be enough space in the nip to release the water vapour, e.g. by introducing a wire in order not to create micro-cracks in the wet web.

In hardboard production, for instance, a high pressure, e.g. 5 MPa, is applied quickly to achieve maximum compression and dewatering. Once the rate of water flow out of the nip falls off and the wet web reaches high temperatures, the pressure has to be partly released, perhaps to about 1.0 MPa, to let the vapour out as featured in W. Mason's original patent. This 1.0 MPa corresponds to wet web temperatures of 180°C and the main evaporation takes place at for example 150°C corresponding to a vapour pressure of 0.5 MPa. The remaining pressure has to be taken up by the fibre network. If this pressure release is not arranged for, the web cracks and can fly out of the press nip. Dewatering before evaporation in hardboard manufacture reaches about 65% dry content[4,5].

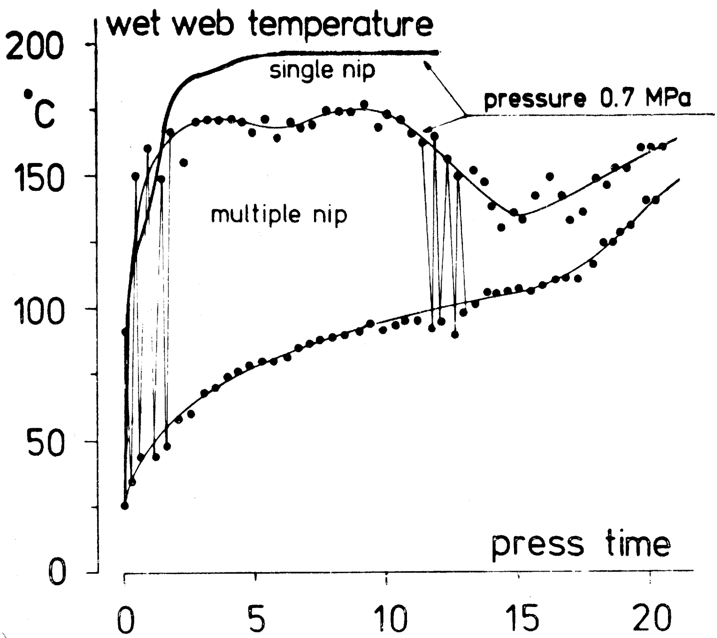


**Fig 2**—Approximate web temperature *vs.* time in single stage and 0.1 sec. multiple stage press-drying, ar 200°C platen temperature and 0.7 MPa external pressure. The web is between gloss platens. The figure indicates how in each nip the temperature rises above 100°C whereafter it falls off below 100°C on pressure release.

Thus press-drying has some potential for energy efficiency. Additional refining reduces the dewatering rate and press-drying temperature at given press platen temperature(6).

In press-drying by multiple nips, the web temperature alternates between a value above and below 100°C on each pressure release as is seen in figure 2(7). The higher the temperature applied in a nip, the larger is the heat transport and drying capacity of such a nip in a given time period, and the smaller the spring back of the wet web. With a press-drying period of 0.1 second a few high pressure nips between platens at temperatures of 350° to 450°C are sufficent for drying as indicated in figure 3(7).

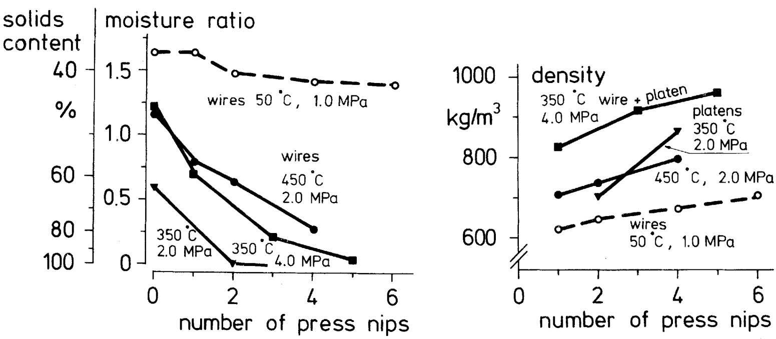


**Fig 3**—The moisture ratio and the final paper density at 50% R.H. and 23°C *vs.* the number of 0.1 sec. press stages for 60% yield kraft paper of 200 g/m². Three types of multiple stage hot nips are applied:

with the web between 320 mesh wires and 450° C platen temperature and 2.0 MPa external pressure

with the web between a 320 mesh wire and a gloss platen using 350° C and 4.0 MPa and

with a web between gloss platens using 350°C and 2.0 MPa

The initial moisture content is also evident in the figure. Data with cold pressing between wires at 50°C and 1.0 MPa are given for comparison. The paper density achieved to the right refers to samples taken out after respective number of nips followed by conventional drying as also used after cold pressing. Strength properties for these papers are given in Fig 11.

If press-drying takes place between one hot plate or hot cylinder and a stretched wire with steam outlet perpendicular to the web, the evaporation cannot take place at a temperature significantly above 100°C. But with sufficient applied pressure and high cylinder temperature it can come near 100°C on average, which might be higher than in conventional drying. If in this case the temperature gradient and the hydraulic pressure in the wet web are too high, problems can arise as outlined below. This 100°C web temperature is one important limitation of the simplest multiple nip press-drying process design for continuous webs, as discussed below. It can only be overcome by adding a metal band outside the wire around the cylinder, or by other extended, hot press nips. The pressure applied as well as the dry content achieved after each nip are also important for the subsequent springback of the web and thus for the bonding area achievable.

Overall heat transport numbers in single stage press-drying of paper between two 150 mesh/inch wires have been calculated[8]. In spite of the inserted wires they are in the same range as in normal cylinder drying[9]. But provided a larger temperature difference can be applied between the heated surface and the web as compared to normal drying, as in single stage press-drying, the drying rates can be significantly increased.

When in press-drying high temperature and pressure are applied rapidly and then partially released, or when the press-drying takes place in multiple stage nips, a density gradient very often appears with the higher density in the outer layers, as illustrated below in figure 19 (see part 2). For medium density fibre building board in the range of 600 to 800 kg/m$^3$, density gradients are used to manipulate product properties[10]. A mill might decide to produce both a panelling grade board with a density gradient to optimise bending stiffness and a furniture grade board with equal density over the caliper so as to optimise the Z-strength and edge screw holding. In a recent study of the mass distribution of TMP papers, similar density gradients were found with a minimum density in the centre in press-dried sheets, compared with the maximum density in the centre of standard papers[11]. This then is a function of the process variables chosen in the press-drying operation. It has to be considered when evaluating the strength properties of such papers.

## Material flow and bonding in press-drying

The press-drying of a high yield pulp might be compared to press moulding of a thermoplastic made up of two or more components with different glass transition temperatures, plus a crystalline component, plus a softener, all distributed in local entities with various relative concentrations. For optimum mouldability and bonding all components should have reasonable flow, achieved by combining sufficient pressure and sufficient temperature.

The viscosity of an amorphous polymer falls off rapidly within a temperature range of 75°C above the glass transition temperature. The glass transition of dry native lignin is about 205°C, that of dry cellulose about 230°C, and that of dry hemicelluloses about 170°C[12,13,14]. Amorphous cellulose and hemicellulose in the fibrous material might be considered to appear as one phase. Lignin is mainly considered as a separate phase (including some hemicellulose and partly bonded thereto), initially enriched in the middle lamella of the cell walls and especially enriched in some types of cells.

Crystalline cellulose in the form of crystallites of melting point about 400°C[15] also occurs. It naturally reduces the flow and the thermal softening possible in this multicomponent system, especially when making up a major part of the material e.g. in cotton fibres. Then, the flow of the remaining, amorphous components at given press conditions mainly determines the bonding area achievable.

Water is a softener for hemicellulose and amorphous cellulose. Therefore it can reduce the glass transition temperatures of these components continuously with increasing moisture content down to 0°C or lower, as calculated and evaluated[16]. Native lignin takes up only a limited amount of equilibrium moisture at 100% R.H., e.g. less than 9%[17] and thus its moist glass transition does not fall below 115°C. For highly sulphonated lignin[18], which takes up more moisture, the lower limit is about 70°C. The total situation then is summarised in figure 4 for TMP and for NSSC medium pulps.

The ordinate to the left gives the glass transition temperature and ordinate to the right a temperature of maximum flow, most suitable as press-drying temperature in the web[19]. This means a drying temperature for TMP pulps of about 200°C and for CTMP or NSSC pulps of about 160° within the web is desirable. Naturally, higher pressure can compensate for a lower web temperature. But in many paper making processes higher temperature can be easier to achieve than higher pressure.

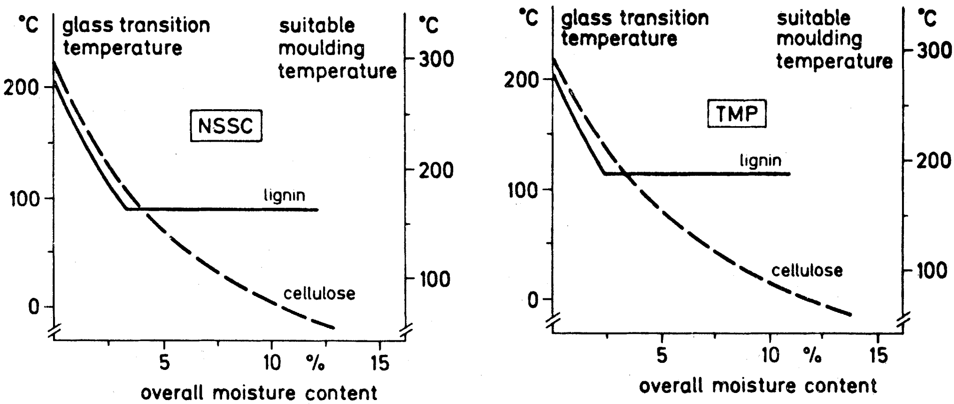


**Fig 4**—Glass transition temperature of TMP and NSSC pulp components respectively as a function of the overall moisture content of the pulp calculated according to the approach of Kaelble. To the right in these figures is given the temperature of optimum mouldability, adding 75°C to the scale on the left. For press-drying of TMP 180°C web temperature and for NSSC 160°C web temperature apparently are most suitable (19).

Also figure 4 indicates the need for higher press-drying temperatures in the web the higher its initial solids content, in order to produce optimum sheet density and strength properties. This is also indicated in figure 5[20].

In water-free or water-deficient conditions, web temperatures near 300°C within the sheet is necessary[21]. At the same time, because of the low thermal conductivity, a large temperature gradient will be needed. This might imply platen temperatures of around 350°C.

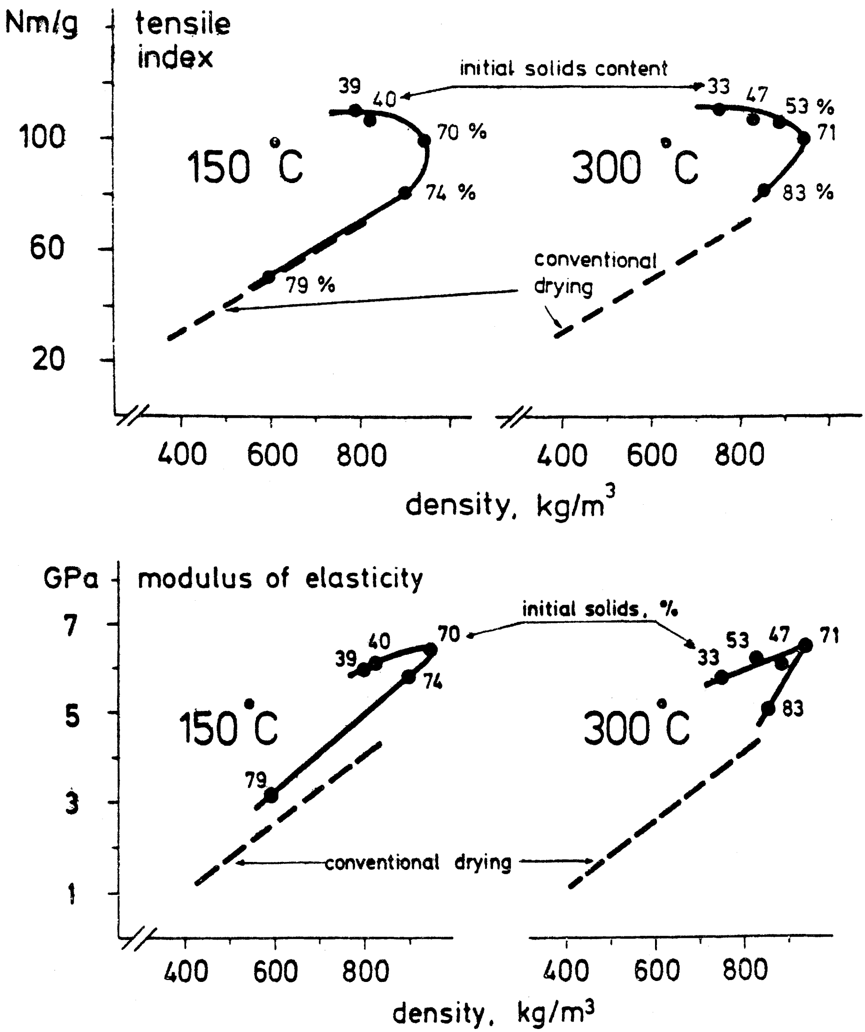


**Fig 5**—Optimization of single stage press-drying in respect to platen temperature for papers of a 60% yield kraft pulp. Tensile strength parameters given as a function of the paper density achieved when using various initial solids content. External pressure is 2.0 MPa and the web is between gloss platens. For comparison data are given for cold pressing at 20°C followed by conventional drying on gloss platens at 60°C. Here the density level of 800 kg/m$^3$ represents the static pressure of 2.0 MPa. The various initial solids content were achieved by pre-drying at 60°C on an oil heated cylinder.

Parenchyma cells which make up all the rays in hardwood and part of the rays in softwoods initially have a much higher lignin content than tracheidal fibres. This is also true for hardwood vessels. On pulping, this difference in lignin content usually increases due to delayed liquor penetration into the parenchyma cells caused by their high content of oleophilic material. The lignin content after pulping might then be three times higher in these cells and vessels than in tracheids. This is summarised in Table 1.

| Species | Ray Parenchyma | | Tracheids | |
|---|---|---|---|---|
| | weight % | lignin content % | weight % | lignin content % |
| Picea abies wood | 3 | 43 | 97 | 26 |
| " standard[a] | 4.5 | 22 | 95 | 7 |
| high yield[a] | 5 | 32 | 95 | 11 |
| rayon pulp[a] | 9[x] | 3.2 | 91 | 0.6 |
| Quercus, wood | 15 | 31 | 70 | 26 |
| Betula, wood | 5 | 25 | 85 | 20 |
| " unbl.kraft | 3.5[x] | 7 | 96.5 | 2.3 |
| " unbl.sulphite | 5.6[x] | 20 | 94.4 | 1.5 |
| NSSC pulp [xx] | 5[x] | 34 | 95 | 20 |

Collected from various sources (22-29)

Vessel elements also usually have a higher initial lignin content and their delignification is slower than that of tracheid fibres.

x) fractionated amount - not necessarily all parenchyma
xx) 90 % betula, 10 % picea wood
a) unbleached sulphite

Table 1
Indicative differences in lignin content
of some cell elements in wood and pulp

In a wet web containing a mixture of fibres or cells the stiffer ones, e.g. those with a high lignin content, limit the overall bonding in standard drying. Press-drying can overcome some of these limitations.

Southern hardwoods are rich in vessels and parenchyma. For some of them press-drying has been shown to have special advantages(30-32). The higher lignin content after pulping in the ray cells and vessls, as compared to tracheids, might be one important reason. Naturally differences in wet stiffness of tracheids from various species can be another reason. Sweetgum (Liquidamba styraflua) contains on volume basis 18% of parenchyma and 55% of vessels(26). Although the weight percentage of these cells and vessels is much less, their relative surface area in the web might make up maybe 30% of the total. So these cells have been shown to be important for the bonding situation(33). The same holds true for Quercus species.

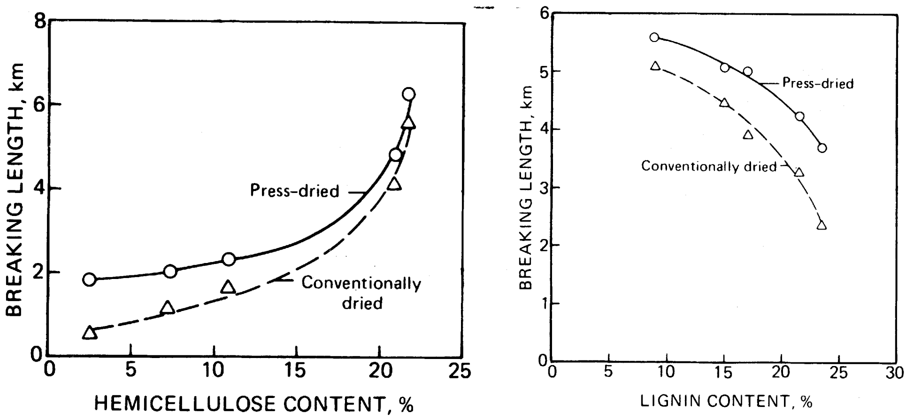


**Fig 6**—The effect of hemicellulose content and lignin content on the benefits of single stage press-drying using 2.8 MPa external pressure and 204°C platen temperature as compared to conventional drying. To the left data refer to a holocellulose from which hemicellulose is extracted stepwise with alkali down to near alpha-cellulose composition. In this lignin free pulp the relative effect of press-drying is most pronounced with low hemicellulose content. To the right the starting point is a high yield kraft pulp from which lignin is removed stepwise by chlorination and careful alkaline washing without removing hemicellulose. Here the relative effect of press-drying is about three times higher with the highest lignin content than with the lowest lignin content. Data of V. Byrd (31).

The main bonding contribution in wet formed paper comes from hemicellulose and amorphous cellulose. Only to a minor extent might native or modified lignin be able to contribute(32). Press-drying has advantages over normal auto-contraction drying, especially with wet-stiff i.e. high lignin, high hemicellulose fibres. It also can have advantages with fibres low in both lignin, hemicellulose and amorphous cellulose i.e. high in wet-stiff crystalline cellulose. Both these types of pulp are difficult to fibrillate and do not comply easily to auto-contraction. Press-drying then in both these cases can be an advantageous alternative to achieve bonding area, as exemplified in Figure 6[31]. Also chemical means to promote fibre swelling can be retained during a press-drying operation.

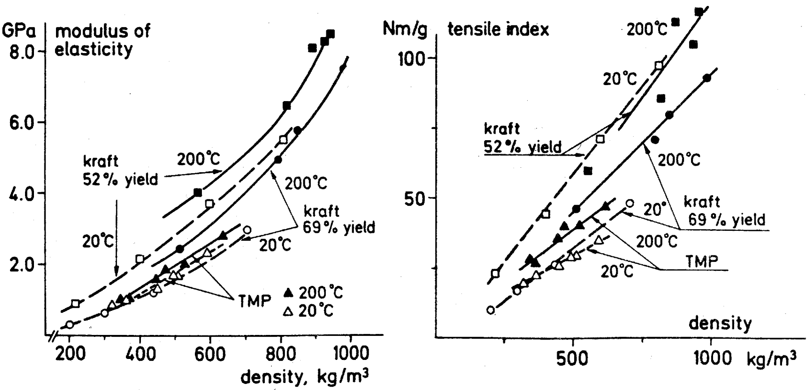


**Fig 7**—Some tensile strength properties obtained by single stage press-drying as a function of paper density compared to cold pressing and conventional drying for Picea abies TMP (triangles) and for Pinus silvestris kraft pulp of 69% (circles) and 52% yield (squares). Press-drying carried out using 200°C and 35% initial solids content with a pressure range of up to 0.8 MPa for TMP pulps and up to 5 MPa for the kraft pulps. At equal density the effect of press-drying as compared to cold pressing and conventional drying is small for standard kraft pulp of 52% yield, but very significant for high yield kraft pulp and for TMP. In all cases, on the other hand, press-drying increases the density range achievable significantly and thereby the strength achievable.

## Effect on paper properties

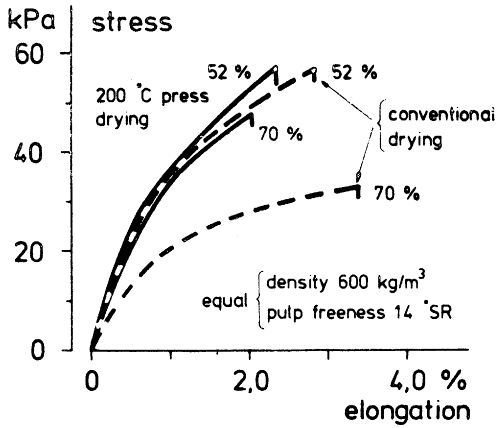


**Fig 8**—Stress strain diagrams of single stage press-dried as compared to cold pressed and conventionally dried papers of standard and high yield kraft pulp. Both pulps were refined to a freeness of 14°S.R. requiring 3 500 and 7 000 revolutions in a PFI mill respectively. The data refer to sheets of equal density, 600 kg/m$^3$, obtained by using different nip pressures, in press-drying at 200°C press platen temperature. Pinus silvestris is wood raw material.

With conventional pulps such as 50% softwood kraft, press-drying is mainly an important alternative to achieve higher paper density and corresponding bonding area. The increased density is thus the dominant factor in the improvement in paper properties. On the other hand in higher yield kraft pulps, in CTMP and in TMP or in some hardwood pulps with a high content of vessels and parenchyma, press-drying at high enough temperature not only produces a high density, difficult to achieve by refining, but as well can much increase the bonding area at equal density compared to conventional drying. This is exemplified in both figure 7, for kraft pulps and TMP[33], and in figure 8. Accordingly, press-drying a kraft pulp of 50% yield at equal density mainly produces additional drying restraints and thus slightly reduces the breaking elongation. With pulp at 70% yield, on the other hand, the tensile strength and modulus is much increased though there is still some reduction in breaking elongation. Also, for higher yield pulps, press-drying improves compression strength, shear strength and shear modulus as well as z-strength compared at equal density. This is illustrated in figure 9[35].

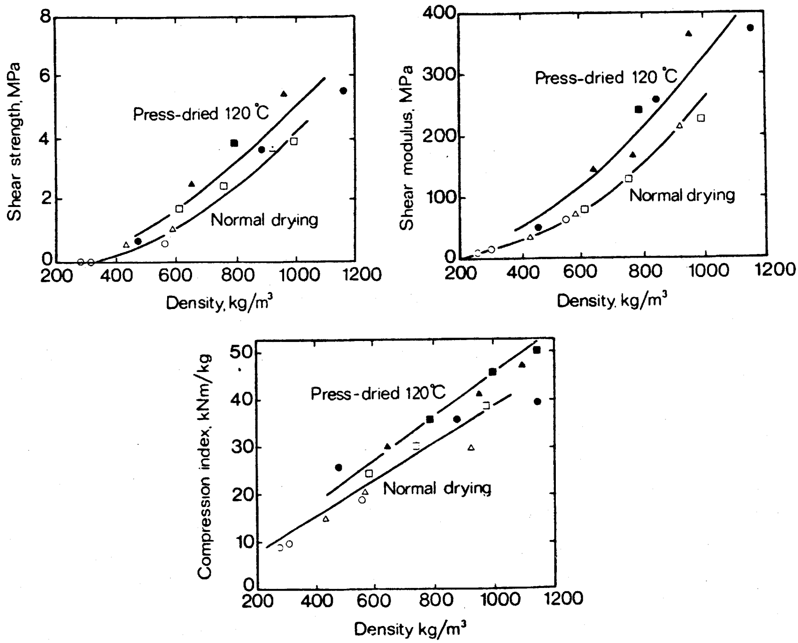


**Fig 9**—The shear strength, shear modulus and compression index of 60% yield Douglas fir kraft pulp when using single stage press-drying at 120°C (solid symbols) or cold pressing followed by conventional drying (open symbols) respectively. Unbeaten pulp of 565 ml CFS (circles), and Valley beaten for 20 min. to 700 ml CFS (triangles) and for 60 min. to 745 ml CFS (squares). Data of C. Fellers (35).

Compared to refining to achieve density, press-drying keeps more of the fibrous structure. It might thus keep slightly more tear strength at a given tensile strength for high yield pulps. On the other hand, in press-drying high yield pulps, the positive effect of refining is still very significant at a given paper density, as shown in figure 10. This is true also for press-drying hardboard to equal density. There, it especially improves the modulus of elasticity, in other words the stiffness, without a significant loss of impact strength: this loss accompanies most other means of improving the modulus, such as using higher press-drying temperatures[36].

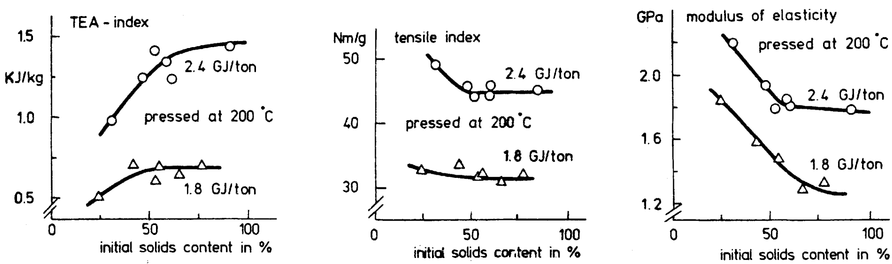


**Fig 10**—Some tensile strength properties for a 60% yield P. silvestris kraft paper produced by press-drying at 200°C platen temperature at a density of 500 kg/m$^3$, all data *vs.* the initial solids content of the web in single stage press-drying and for two levels of refining with the total refining energy given. 1.0 GJ refers to 278 kWh. As is apparent from these data, the relative effect of refining on strength properties is highest initial solids content in the single stage press-drying operation.

In multiple stage press-drying, when the pressure applied initially has to be released completely or partly before the paper is dry, there is always some springback and loss in strength properties compared to single nip press-drying, even if compared at equal density[7,37]. Thus there is no gain in strength at equal density, though a higher density is achievable when compared to normal drying. This can be partly compensated for by increasing the press-drying temperature stepwise in the multiple nips[7], as shown in figure 11. The characteristics of these nips naturally govern the paper properties achieved.

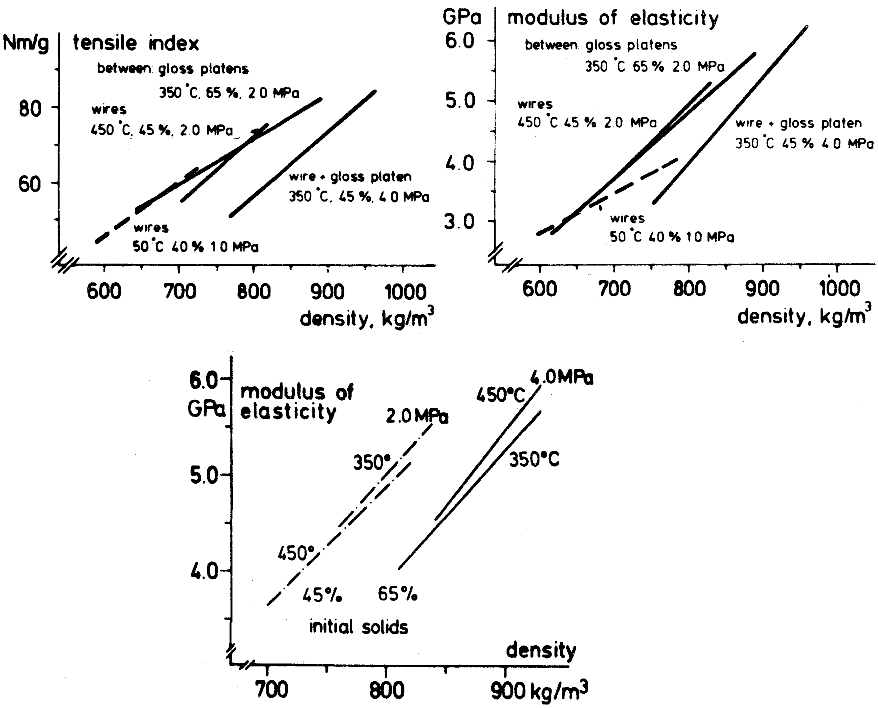


**Fig 11**—Tensile properties for 60% yield P. sivestris kraft paper in various means of multiple stage press-drying operations using 0.1 sec. hot press nips. Two figures to the left refer to those in Fig 3. One illustrates the effect of temperature for two initial solids content when press-drying in these 0.1 sec. stages between two wires of 320 mesh/inch.

As regards sizing, there is less surface area to be covered on a press-dried paper than on one that has been refined. With a high enough press-drying temperature, such as 250°C or above, some auto-crosslinking with wet strength and wet stiffness and swelling restrictions as well as dry strength and stiffness will be introduced at least into the outer layers of the paper. Some of these additional effects of high temperature press-drying are exemplified in figure 12 for hardboard[38]. A high lignin content pulp also retains some fibre swelling restriction, and thus dimensional stability[39] and some wet strength[31]. Especially significant in this high temperature effect is an increase in z-strength due to auto-crosslinking[40].

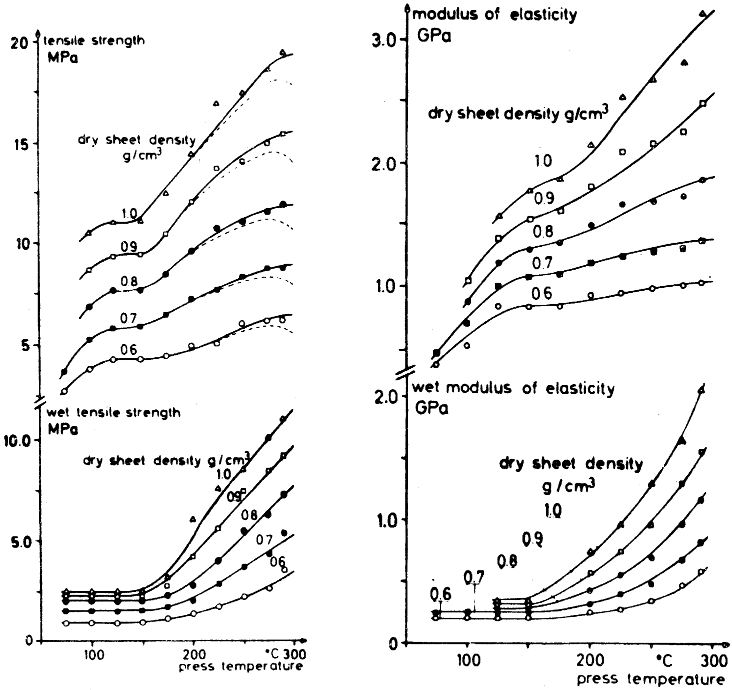


Fig 12—Tensile strength properties of hardboard as a function of the press temperature over a range of board densities. Tensile properties are given both in the dry state at 65% R.H. at 20°C and in the wet state after 24 hours of water immersion at 20°C. As obvious from these data there is not only a considerable increase in dry strength properties with temperatures above 200°C, but also a very pronounced increase in wet strength properties above this temperature especially at high board density. These boards were only press-dried, not heat treated.

On the other hand such auto-crosslinking can result in embrittlement and a reduction in impact strength. If by press-drying improved strength parameters are achieved by increased density, implying reduced caliper, the stiffness of the paper, the product of the moment of inertia and modulus of elasticity, is reduced significantly. For some paper grades, like normal basis weight liner or corrugating medium this is no disadvantage, but for others it might well be and has to be considered.

## REFERENCES

1. Moore, J.H. and William H. Mason
Southern Industrial J. Southern History, 1961, **27**(2), p.169
2. Setterholm, V. and Aucher, R.J.
USDA Forest Serv. Res. Pap., 1975, FPL 256
3. Anderson, R. and Back, E.L.
Report to the 1959 Foundation of the Pulp & Paper Ind. Jan. 1975 and Medd. Svenska Träforskningsinst., 1976, **B**:392
4. Jennsjö, H. and Back, E.L.
Medd. Svenska Träforskningsinst., 1979, 548
5. Back, E.L., Bucko, J., Björklund Jansson, M.
Svensk Papperstidn., 1978, **81**, p.153-155
6. Sandström, E., Back, E.L. and Nordin, S.
Medd. Svenska Träforskningsinst., 1977, **B**:455
7. Back, E.L. and Anderson, R..
Svensk Papperstidn., 1979, **82**, p.35-39.
8. Byrd, V.L., USDA For. Serv. Res. Pap., 1979, FPL **338**
9. Spraker, W.A., Chapter in 'Drying of Paper and Paper Board' Ed. G. Gavelin, Lockwood Publ. Inc., 1972
10. Sandström E. and Nordin, S.
Medd. Svenska Träforskningsinst., 1976, **B**:376
11. Kimura, M. and Mark, R.E., Manuscript in preparation
12. Goring, D.A.I., Pulp Pap. Mag. Can., 1963, **64**, T 517-527
13. Back, E.L. and Didriksson, E.I.E.
Svensk Papperstidn., 1969, **72**, p.687-694

14. Salmén, L., Pulp Pap. Can., Trans. Tech. Sec., 1979, **5**(3), TR 45-50
15. Back, E.L., Nordin S.B. and Nyren, J.O. Textile Res. J., 1974, **44**, pp.152-54, and pp.915-17
16. Salmén, L.N. and Back, E.L., Tappi, 1980, **63**(6), p.117-120
17. Cousins, W.J., Wood Sci. Technol., 1976, **10**, p.9-17
18. Atack, D. and Heitner, C Pulp Pap, Can., Trans. Tech. Sec., 1979, **5**(4), TR 99-108
19. Back, E.L., Salmén, L. and Wiken, J.E. Medd. Svenska Träforskningsinst., 1981, **B**:572
20. Anderson, R.G. and Back, E.L. Pulp Pap. Mag. Can., 1976, **77**, T 260-263
21. Back, E.L. Wahlström, C.G. and Anderson, R.G. Tappi, 1979, **62**, p.89-92
22. Hardell, H-L., Leary, G.J., Stoll, M and Westermark, U. Svensk Papperstidn., 1980, **83**(2), p.44-49
23. Back, E.L., Svensk Papperstidn., 1960, **63**, p.695-698
24. Furuya, N., Bull. Gov. For. Exp. Stn. (Jpn), 1974, **263**
25. Fergus, B.J. and Goring, D.A.I., Holzforschung, 1979, **24**(4), p.118-124
and Pulp Pap. Mag. Can., 1969, **69**, T 314-322
26. Rydholm, S., Pulping Processes, Interscience Publ., New York 1967, p.49
27. Malm, E. SCA, Sundsvall 1958 and Swan, B., Billerud Unpublished data
28. Harlow, W.M. and Wise, L.E. Ind. Eng. Chem., 1928, **20**, p.720-22
29. Sihtola, H., Chapter 14 in Puukemia, Editor W. Jensen, Åbo 1977
and Sihtola, H., Saarinen, A, Wigren G., Ulmanen, T and Saxén, E., Paperi ja Puu, 1956, **38**(4A), p.221-226.
30. Setterholm, V.C., Tappi, 1979, **62**(3), p.45-46
31. Byrd, V.L., Tappi, 1979, **62**(7), p.81-84
32. Horn, R.A., Tappi, 1979, **62**, p.77-80
33. Marton, R., Goff, S., Brown, A.F. and Ganzow, S. Tappi, 1979, **62**(1), p.49-53

34. Anderson, R., Back, E.L., Salmén, L.N. and Wahlström, C.G. Medd. Svenska Träforskningsinst., 1977, **B**:463
35. Fellers, C., Data to be published
36. Norberg, K.G. and Back, E.L., Svensk Papperstidn., 1969, **72**, p.649-655
37. Yang, C.-F., Mark, R.E., Eusufzai, A.R.K. and Perkins, R.W. Svensk Papperstidn., 1981, **84** (in press)
38. Norberg, K.G. and Back, E.L. Svensk Papperstidn., 1968, **71**, p.774-787
39. Back, E.L. in 'The Fundamental Properties of Paper Related to its Uses' Editor F Bolam, London, 1976, pp.811-813
40. Stenberg, E., Svensk Papperstidn., 1978, **81**, p.49-54

# Transcription of Discussion

**Discussion following paper given in two parts by Prof. E.L. Back, and Mr. R. Swenson.**

Dr. R.E. Mark, ESPRI, USA

Dr. Back, in your presentation you said that wet strength properties were improved by your treatment. I didn't see any graphs to support that statement, nor do I see any in your paper. What are the results of any experiments you have performed in connection with this?

Prof. E.L. Back, STFI, Sweden

Figure 12 in the paper shows the wet and dry strengths and the wet and dry moduli as functions of temperature and pressure. These results refer to fibre building-board. We have only a small amount of data showing the same results for paper. The improvement in wet mechanical properties seems to depend on the press-drying process, since it is greatly reduced if press-drying is stopped at 80% solids.

Mr. V.C. Setterholm, FPL, USA

I would like to add to Profesor Back's answer that we measured the wet strength of press-dried oak fibre box-board to be about 7% of its dry strength. Since this figure would normally, with conventional drying, be about 2%, there does seem to be a considerable improvement. The extra 5% would have an enormous effect on the compression-creep properties of liner-board.

Dr. L. Nordman, The Finnish PPRI

The authors have been talking about the strength properties of press-dried board. It has also been mentioned that liner-board production is a possible application of press-drying. However, when liner-board is glued to corrugating medium there must be some absorption to produce any adhesion. How does press-drying affect water absorption, wettability, and so on?

Mr. V.C. Setterholm

We encountered very few problems, since press-dried material tends to be more absorbent. The main difficulty our operators encountered was that of excessive stretch. We found that it helped performance if we press-dried our corrugating medium also so as to match the strength of the liner-board.

Prof. E.L. Back

The speed of wetting might be slightly reduced by the increased density.

Mr. R. Swenson, International Paper, USA

We found that if excessive case hardening is applied to the liner-board surface then the best test for glueability is the degree of penetration of a water drop.

In severe cases of high temperature press-drying a two sided effect becomes apparent, which can necessitate modifying the glue formulation, perhaps with a wetting agent, in order to achieve adequate penetration.

Dr. D. Wahren

Do you think hot press-drying can be performed on the paper machine?

Mr. R. Swenson

I don't know, and I don't think it is up to us to say yes or no. We have shown that the concept can be applied, and I believe it is up to the machinery builders to produce the technology.

Mr. V.C. Setterholm

It was a few years after the Wright Brothers' flight before the first 747 flew, but I think the adoption of press-drying will be quicker because the advantages are so enormous.

The TAPPI Technology Transfer Committee predicted that the first commercial press-drier would run in 1986. I think it will be in operation before then.

Prof. E.L. Back

It took William Mason less than a year to start the first hardboard mill in Laurel, Mississippi.

Mr. E.J. Justus, Beloit Corporation, USA.

We haven't completely solved your problem yet, though we are half way there. We have found that by extending the pressing time we can increase the dryness of the sheet after pressing, increase its density, and improve its physical properties, strength, ring crush, and internal bond.

Mr. R. Swenson

Indeed, increasing pressing time in the wet press section does improve the sheet properties, even at ordinary sheet temperatures. The degree of this improvement will be limited by the potential of the pulp, and for high-yield and hardwood pulps will not be considerable. Where the hot press-drying effect really becomes significant is in improving the properties of material made from lower quality pulps.

Mr. A. de Ruvo, STFI, Sweden.

What actually happens in hot press-drying is that the lignin is softened by the application of high temperature and pressure under humid conditions. This softening allows the lignin to flow under the applied pressure, so that a high sheet density is obtained. I would like to know how this is different from the behaviour of semi-chemical pulps, where the lignin softening is achieved by the ionisation of a sulphonate group. We make semi-chemical pulps from birch, which is very strong and dense, and whose only disadvantage is brittleness. Have you considered enhancing your densities chemically?

Mr. V.C. Setterholm

Yes, we have tried that. We have press-dried liner-board made from 80% yield semi-chemical pulp on our machine, with considerable success.

Mr. R. Swenson

The softening temperature is reduced with greater sulphonisation of the lignin, which helps the press-drying process. But since NSSC is no longer a viable process for a new installation in the USA, we are not considering it any further.

Dr. G.A. Baum, IPC, USA

It seems to me that the one parameter you have not considered is time. We have performed cold pressing experiments in which we have maintained the pressure until the sheet is dry, and obtained resulting sheet strengths quite comparable to those obtained with hot press-drying for a shorter time.

Prof. E.L. Back

Were you using high-yield pulps?

Dr. G.A. Baum

The yields were around 50%

(The remainder of this contribution was added afterwards, and thus may not form a strict sequitur with the rest of the discussion, ed.)

The figure shows tensile index for cold press-dried samples plotted as a function of apparent density. The loblolly pine samples were separated into early- and late-wood fractions, and none of the samples was refined. The six data points are reproduced from Forest Products Laboratory report FPL 295, 1977, and illustrate the differences in physical properties obtained by hot and cold press-drying, on three different high-yield pulps.

Although the IPC samples were of lower yield, these results suggest that time, as well as temperature and pressure, is of importance in bringing about the improvements associated with hot press-drying.

Prof. E.L. Back

Did you find improved strength properties at constant density? That is one of the important achievements of press-drying high lignin pulps. The straightforward density increase resulting from wet pressing does, of course, lead to improved strength properties.

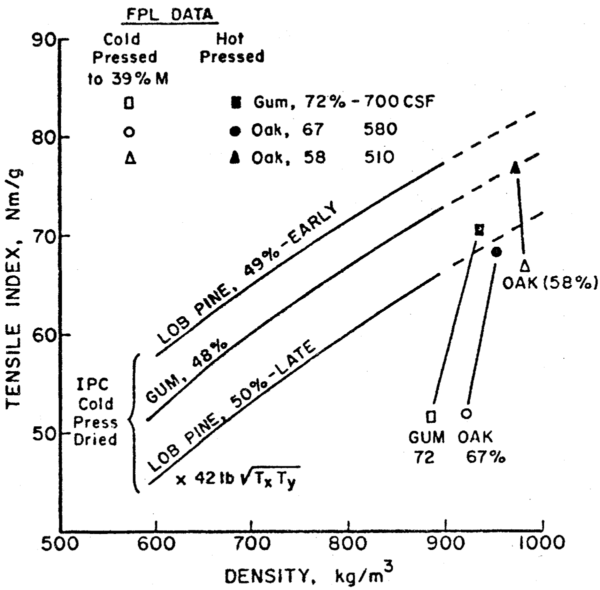


Fig 2

Dr. G.A. Baum

The density was increased, with a corresponding improvement in the mechanical properties.

Prof. E.L. Back

Ah, but true press-drying enhances the mechanical properties at equal densities. The differences in the effects of high temperature pressing high- and low-yield pulps are seen at constant density. Figure 1, and those following, in my paper shows this.

Dr. Wahren

Mr. Setterholm, didn't you say that you got the press-drying effect at low temperatures?

Mr. V.C. Setterholm

Yes, indeed. There is a press-drying effect on high-yield pulps at low temperatures but in our experience the strength enhancement obtained is only about 2/3 that obtainable at higher temperatures.

Dr. R.P. Taylor, American Can

Would one of the authors please comment on the effects of press-drying TMP?

Prof. E.L. Back

Figure 7 of my paper illustrates some results showing the effect of press-drying on the strength properties of various pulps, including TMP. The effect on TMP is relatively greater than on the high-yield kraft pulps. In principle, the effects of press-drying should be at least partly achievable on completely dry pulp. With temperatures around 300-350$^{o}$C even completely dry fibres can be bonded, provided that the glass transition temperature for one of the fibre components is exceeded. This is easier for TMP than for delignified pulp.

Dr. F.J. Loprest, American Can

What is the density gradient through the sheet produced by press-drying? Do you have any data on this, especially on the increase at the surface?

Mr. V.C. Setterholm

We have not found a large density gradient.

Prof. E.L. Back

Building-board not uncommonly has a density at the surface of as high as 800 kg/m$^3$, while that at the centre is only 500 kg/m$^3$. Dr. R.E. Mark has measured these gradients and might be able to answer this question.

Dr. R.E. Mark, ESPRI,USA

We haven't performed this investigation quantitately on a large number of specimens. But Dr. Kimura, my former colleague, did perform such analysis of conventional TAPPI and press-dried hand-sheets. I shall illustrate his results later.

Dr. D.H. Page, Paprican

Do I understand correctly that you can make liner-board, or rather a sheet with the properties of liner-board, using an 80% yield hardwood kraft pulp?

Mr. V.C. Setterholm

We use the rule 41 US Consolidated Freight Classification of 100 points burst per 42 lb (200 g). On that basis we can meet the requirements and make a suitable liner-board from 80% semi-chemical pulp. It is not as good as that obtained from a low yield pulp.

Dr. D.H. Page

How do you run an 80% yield hardwood kraft pulp through the wet end of a paper machine at the speeds liner-board machines run at?

Mr. V.C. Setterholm

That's out of my province, but considering the enormous potential financial returns it seems to me that, if necessary, we should be able to deliver sand to a press-drier!

Mr. R. Swenson

The high yield kraft pulps we have worked with were not as high as 80%, they were nearer 65-70%. However, the freeness was very high, since we don't refine below 600 CSF; we just defiberise what comes out of the digesters. With such a high freeness we feel that the drainage rate is adequate to produce a sheet.

Dr. R.E. Mark

The figure illustrates the results we obtained from our experiments to determine the density gradients in sheets dried under different conditions. Curve A in the figure shows the density gradient of more conventional paper, while curve B shows that for press-dried paper.

Across the surface of a conventional sheet there is a gradual increase in density, reflecting the presence of loose fibres at the surface. There is also a slight crown, with the sheet showing a higher density at the centre than at the edges. The curve is, of course, symmetrical.

The density curve of a press-dried sheet, however, rises much more rapidly across the surface, reflecting the relatively greater surface densities of such sheets. There is also a dip at the sheet centre.

We concluded that the press-dried sheet density distribution would give rise to a change in the centroidal moment of inertia, with a consequent change in bending properties (i.e. increased beam stiffness), all other things being equal.

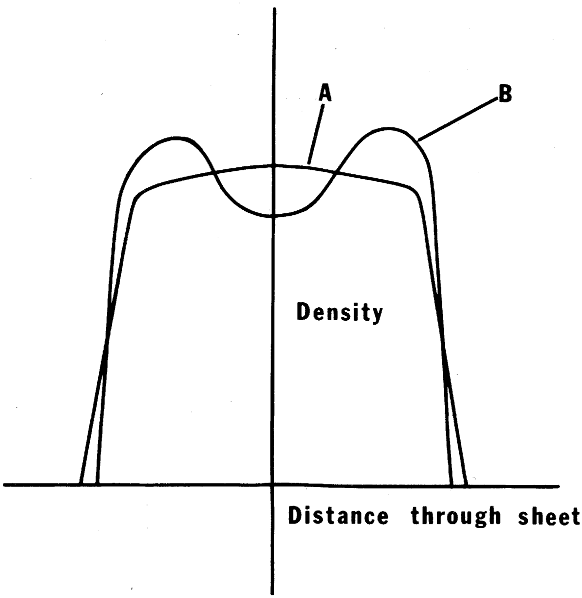


Fig 3