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DRYING STRATEGIES AND A NEW RESTRAINT TECHNIQUE TO IMPROVE CROSS-DIRECTIONAL PROPERTIES OF PAPER

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ABSTRACT

Machine-made papers often have an unsatisfactory cross-direction profile with regard to their mechanical properties. The edges often have a lower strength and stiffness than the middle of the web.

Laboratory studies of the behaviour of paper during drying have shown the potential of improving CD properties without any deterioration in MD properties. This is achieved by preventing paper shrinkage in both directions during drying.

After extensive trials on a full-size paper machine equipped with a new cross-direction restraining technique, it has been demonstrated that the laboratory results can be repeated in a continuous process. This invention has the potential of solving some old problems in papermaking such as evening out the cross-direction profile and improving strength and stiffness properties, dimensional stability and surface properties.

INTRODUCTION

In conventional papermaking, after forming and pressing, the paper web is dried either in cylinder dryers or in cylinder dryers in combination with air-borne dryers. These processes not only remove water but also have a great influence on the paper properties. It is for example well established that a decrease in shrinkage during drying leads to an increase in bending stiffness as well as in tensile and compression strength properties and to a decrease in toughness-related properties. Shrinkage during drying also affects surface smoothness and dimensional stability in a negative way.

In the paper machine, MD-strains can be controlled with satisfactory precision but shrinkage in the CD is relatively uncontrollable. This means that the MD-properties of the paper are often uniform across the width of the machine whereas CD-properties always vary. By taking samples along the drying section of the paper machine and drying the sheets under restraint the action of the drying section can be studied. It can be established that in a full-size paper machine the strength can be increased through the drying section through wet straining in the MD whereas the strength in the CD decreases gradually because of shrinkage (1).

Straining in the MD during the drying can affect the strength properties in the CD both positively and negatively. A negative CD-influence can be related to cross-machine contractions. On the other hand, contact with the drying cylinders can be improved, which reduces the CD-shrinkage, so that the strength properties in the CD are improved. Which of these effects finally predominates is dependent on factors such as the design and size of the dryer section, the existence of a drying felt, the felt tension, and the length of the free draws.

Many fundamental studies of paper drying have been performed over the years, and these form the foundation of the work presented here. References to these works are given in earlier publications by the STFI authors and only those of particular importance in the present context are referred to in this article.

The first part of this article describes the fundamental drying studies performed at STFI, both in laboratory tests and on commercial paper machines concerning the effect of drying strategies on the mechanical properties of paper.

On the basis of these laboratory results which showed, for example, that properties in the MD and CD can be affected independently of each other, extensive development work has been carried out by STFI in collaboration with Fläkt Industri AB. The collaboration concerns a drying technique which offers drying restraint in both the MD and CD. Results from tests on a paper machine equipped with this technique are presented.

PRESTUDIES - RESULTS AND DISCUSSION

The sheet property potential before drying

Fibres which usually form the building bricks in a paper consist of strong and stiff cellulose fibrils embedded in a matrix of hemicellulose and lignin. These three polymers form a strong and stiff composite. In its original state after fibre separation the fibre is not yet suitable for papermaking. It must be treated further, primarily through beating. The fibre's concentric construction with its lengthwise cellulose fibrils means that swelling takes place during beating mainly in the cross direction while the swelling in the length direction is considerably less.

The increased swelling and fibrillation and the creation of new surfaces and fines make the fibre inclined to bonding. The beating of the fibres thus prepares these so that a suitable sheet structure from a paper technology viewpoint is obtained during the sheet forming and pressing operations.

If this property potential created during beating, forming and pressing is to be used in an optimum manner, the drying must be adapted to the demands on the properties of the final product. For sack paper, for instance, the paper shall be allowed to shrink to a maximum in order to obtain high toughness. To use the potential in paper where high stiffness and high strength are important, the paper shall be dried under restraint or even be stretched during the drying.

The viscoelasticity of paper during drying

The viscoelasticity of polymers, i.e. their time-dependent mechanical properties, are characterized by studies of creep and stress relaxation and by studies of changes in stiffness and internal friction (tan δ) during cyclic loading.

From measurements of the temperature dependence of the viscoelastic properties of polymers, knowledge can be obtained concerning how a given polymer can be influenced during a cooling process in order to obtain suitable mechanical properties. A maximum in tan δ is obtained at the temperature Tg (the rubber-glass transition temperature). In the temperature range around Tg it is possible to straighten out and orientate the separate molecule chains in a permanent way by straining since the material is soft but still has so high a viscosity that the friction between the molecule chains is marked. The high viscosity also means that it will take a relatively long time for the molecule chains to revert from the oriented state, even though they strive to do so all the time.

If the polymer is strained at a temperature around Tg and the temperature is thereafter reduced until it has dropped to the polymer's glassy state the state of orientation is made permanent. In this way the stiffness and strength of the polymer are improved (2).

At temperatures lower than Tg it is very difficult to orientate a polymer since the molecular mobility is very limited. By analogy with the effect of the temperature on synthetic polymers, water and heat function as softeners for paper which consists of natural polymers.

The cellulose in the paper fibres consists both of crystalline and disordered (amorphous) zones. The crystalline zones are inaccessible to water. The disordered zones absorb water more easily, and this causes the cellulose structure in the moist state to be soft. During the drying process the stiffness of the cellulose structure is gradually increased.

The hemicellulose in the matrix is mainly disordered and soft during most of the drying process and is stiffened only towards the end of the drying. The lignin is essentially stiff during the whole drying process at temperatures below 100°C.

The viscoelastic properties of paper during the drying process have been studied as shown in Fig. 1, (3).

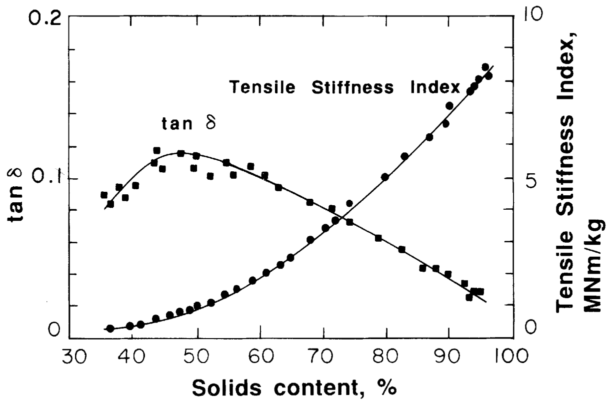


Figure 1 Viscoelastic properties of paper during drying, where tan δ is the internal friction, a measurement of the mobility of the cellulose structure, (3).

Fig. 1 shows tan δ and tensile stiffness index versus solids content during the drying process for a paper of bleached sulphate pulp. The sample has been dried under restraint. We see that a maximum in tan δ for paper is found in the solids content range of 40-55 %, and that the tensile stiffness index of the sheet increases dramatically after the maximum in tan δ has been passed.

A physical transformation of the state of the paper sheet has taken place and the tensile stiffness of the sheet has increased. This phenomenon is analogous to the rubber-glass-transition of amorphous polymers and implies, according to the polymer analogy, that the paper sheet is most easily influenced in the vicinity of the maximum in tan δ, i.e. in the solids content interval around 50 %.

If the paper is dried freely near the maximum in tan δ, a high strain to failure and a high tensile energy absorption index should be obtained. If the paper is dried under restraint or is wet strained in this solids content range, a strong and stiff paper should be obtained.

The shrinkage of paper during free drying

During the forming of the sheet, the fibres form a network where the fibres bond to each other at the cross-over points. Fig. 2 shows an idealized picture of a paper sheet before and after drying. When the swollen fibres begin to dry the fibres shrink, the changes in dimension occurring mostly in the transverse direction. Microscopic studies of a fibre cross-over point in a freely dried sheet show that the transverse shrinkage of one fibre compels a longitudinal compression causing creases of the other fibre. Such creases are usually referred to as micro-compressions. The greater the degree of free drying to which the paper is exposed, the more pronounced are the micro-compressions, (4), (5).

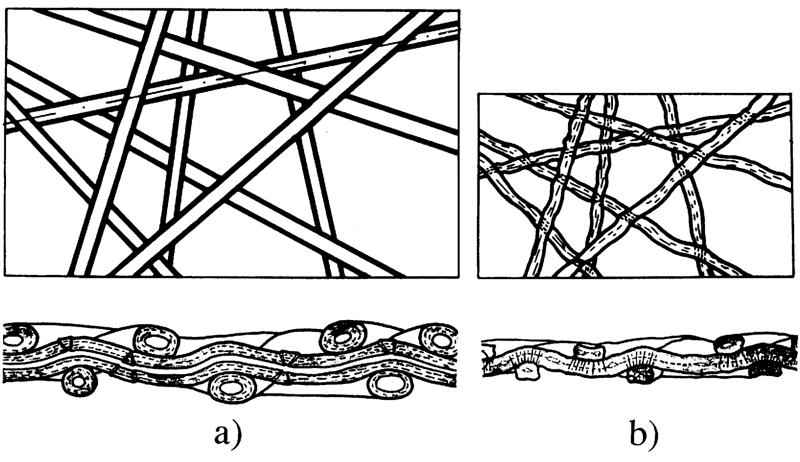


Figure 2 The Page-Tydeman effect during drying a) swollen fibre structure before drying b) fibre structure after free drying, (4, 5).

That a fibre can be compressed in its length direction by the transverse shrinkage of a crossing fibre in spite of its stiff and strong cellulose fibrils can be explained by the fact that, in a moist condition, the fibre structure is soft and that local dislocations or transverse displacements in the walls of the fibres can take place. Dislocations can be initiated locally at faults along the fibre at different structural levels in the cellulose structure.

In a paper machine, the web shrinks mainly in the cross-machine direction because a machine-made web always has more fibres oriented in the machine direction and because the shrinkage of a fibre is greatest in the transverse direction of the fibre. In principle, the shrinkage develops during the free drying of paper according to Fig. 3, the greater part of the shrinkage occurring in the solids content range of 60-80 %. The magnitude of the shrinkage which occurs depends among other things on the degree of swelling of the fibres and on the fibre orientation in the paper.

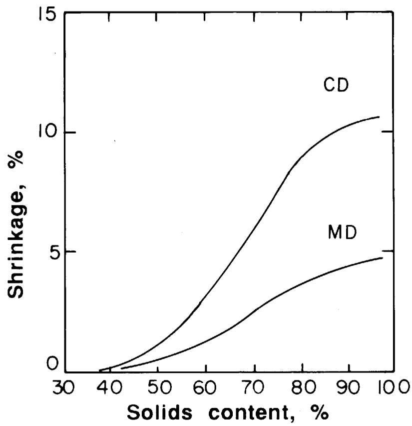


Figure 3 Shrinkage versus solids content of a bleached sulphate paper 25SR.

The degree of swelling of the pulp increases with increased beating, and this also gives a greater shrinkage during drying. Fig. 4 shows the shrinkage of laboratory sheets of hardwood and softwood at different swelling levels, measured as WRV (Water Retention Value). This experiment shows that an increase in fibre swelling leads to an increase in shrinkage. That different results are obtained for different sort of fibre at the same WRV suggests that structural factors in the paper also affect the shrinkage (6).

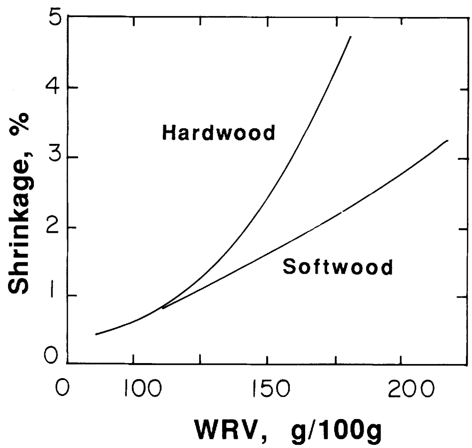


Figure 4 Shrinkage versus swelling (WRV) for softwood and hardwood (6).

Drying forces

If a paper is prevented from shrinking during the drying process large forces develop in the plane of the paper. These can be measured in the laboratory by fastening the paper in clamps and measuring the external forces. Fig. 5 shows how the drying force for a paper increases with increasing solids content. The drying force at a given solids content in a given direction increases with increasing fibre orientation in that direction. This differs from the shrinkage of the sheet during free drying, which decreases with increasing fibre orientation (Fig. 3). The reason for the large drying forces in the MD, although the fibre strives to shrink only a small distance lengthwise is that there are more fibers orientated in the MD and that the fibres have a higher longitudinal stiffness than the transverse stiffness.

At low solids contents the fibres still have a low stiffness which causes relatively low drying forces in the paper. At higher dry contents, the fibre stiffness increases, and as a result, the drying forces increase strongly.

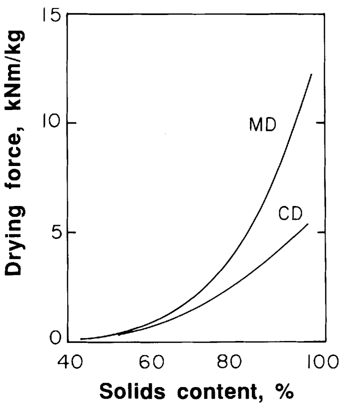


Figure 5 Drying force during restrained drying versus solids content for MD and CD of a bleached sulphate paper, 25SR

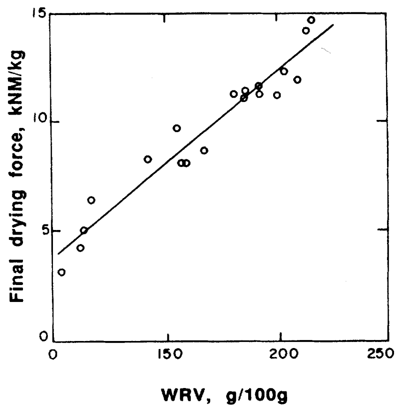


Figure 6 Final drying force restrained drying versus swelling (WRV) for different pulps.

The level of the final drying force in a conditioned climate corresponds to the force which is obtained at about 0.1 % strain in the dry sheet (3). As in the case of the shrinkage, the final drying force is increased to a great degree by the initial swelling of the fibres as is shown in Fig. 6.

Increased beating or other swelling-promoting measures have a positive effect on the stiffness of the sheet if shrinkage is prevented. There is a clear connection between the final drying force during restrained drying, and the mechanical properties of the paper. As an example, Fig. 7 shows the effect of the final drying force on the tensile l stiffness index of paper for a number of different pulps. Similar linear relationships are also valid for tensile index and compression index.

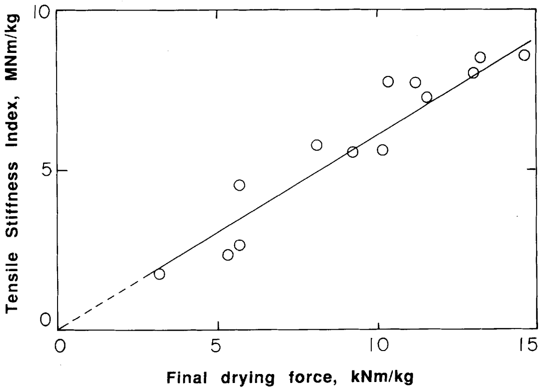


Figure 7 Tensile stiffness index versus final drying force during restrained drying for different pulps.

In a paper in the wet state, there is always a spectrum of more or less strained fibres. Fig. 8a illustrates a crooked fibre in a fixed positon (L), with crossing bonded fibres (T) before the drying. After the drying, Fig. 8b, the fibres (T) have shrunk in their cross-direction, as described earlier. As a consequence, the fibre segments between the crossing points in a paper dried under restraint will be strained partly by the longitudinal shrinkage of the fibres and by the few micro-compressions which are nevertheless formed. During loading of the paper in the dry state, it is the straight, strained fibre segments which first take up the load. It can therefore be said that during drying under restraint the majority of the original fibre segments in the network are transformed from being crooked and passive to being active load-bearing fibre segments, which gives the sheet high strength and stiffness. This phenomenon is sometimes called the Giertz effect (7).

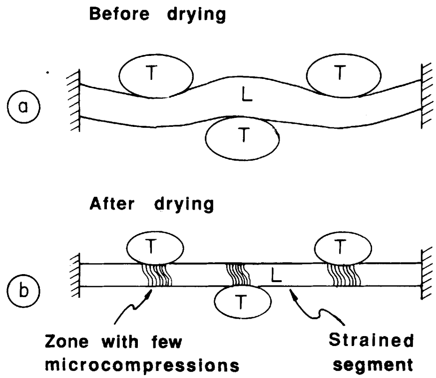


Figure 8 The Giertz effect(7). a) Swollen fibre structure before drying, b) Fibre structure after drying. Longitudinal fibres (L) are straightened during restrained drying. Due to fibre segment shrinkage in the longitudinal direction (L) and micro-compressions due to shrinkage of transverse (T) fibres.

Influence of fibre orientation

Paper is in general an anisotropic material, which means that the mechanical properties are different in different directions. There are however, certain axes of symmetry which for a machine manufactured paper are the machine-direction (MD) and the cross-direction (CD). Paper can therefore be considered to be an orthotropic material in the plane of the sheet. An increase in fibre orientation makes the paper stronger and stiffer in the MD, while the corresponding properties decrease in the CD. This is exemplified in the case of the tensile stiffness index in Fig. 9, (8).

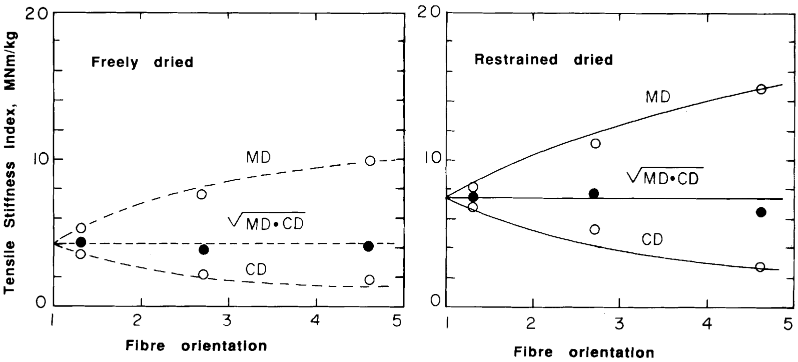


Figure 9 Tensile stiffness index versus fibre orientation for bleached sulphate papers 21SR. If the drying conditions are the same in MD and CD, the mean geometric value is constant for different fibre orientations, (8).

The fibre orientation is defined in this and subsequent figures as the MD/CD-ratio for tensile index after drying under restraint.

If the drying conditions are the same in the MD and the CD, the geometrical mean value is constant independent of the fibre orientation. The geometrical mean value changes with drying conditions in such a way that an increase in the shrinkage reduces the tensile stiffness index.

In principle the same is valid for the tensile index and the compression index, (8).

After drying under restraint in both the MD and CD, the strain to failure is the same in both directions and thus independent of the fibre orientation, as is shown in Fig. 10. It is the straining of the fibres which lie in the loading direction which determines the strain to failure for the paper.

The number of such fibres determines how strong the sheet is but not the strain at which they break. This result has also been reported by Setterholm and Kuenzi, 1970, (9).

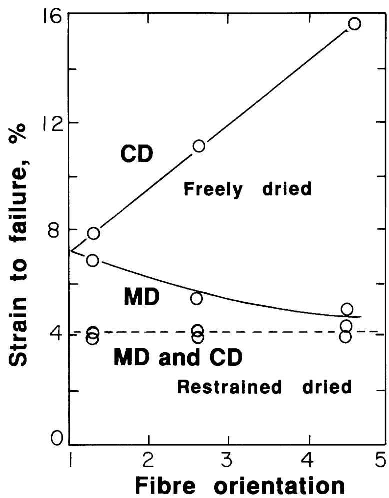
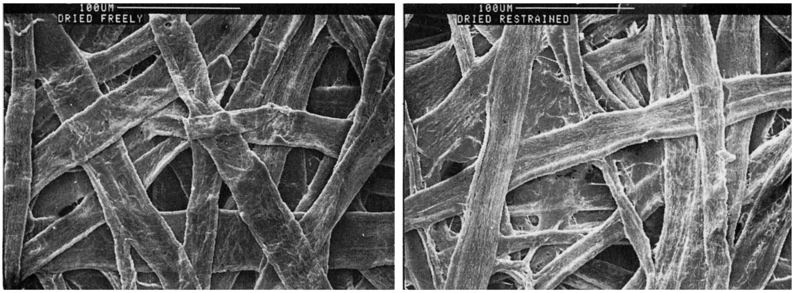


Figure 10 Strain to failure versus fibre orientation for free and restrained drying. Same pulp as in Fig. 9, (8).

Since during free drying paper shrinks more in the CD than in the MD, the strain to failure after such drying decreases in the MD and increases in the CD with increasing fibre orientation.

The appearances of the fibres (a) after being dried freely and (b) dried under restraint are compared in Fig. 11. The fibres are relatively straight after being dried under restraint whereas they adopt a more curled form in the freely dried state, (10).



a) b)

Figure 11 A comparison of the appearance of the fibres, a) after free drying, and b) after restrained drying. Decrilled bleached sulphate paper, (10).

The reason for the differences in mechanical properties between restrained and free drying can be related to the shape of the fibres and to the degree of micro-compressions mentioned earlier.

Results from laboratory studies in which the shrinkage in the MD and CD has been varied systematically are shown in figures 12 and 13, (11).

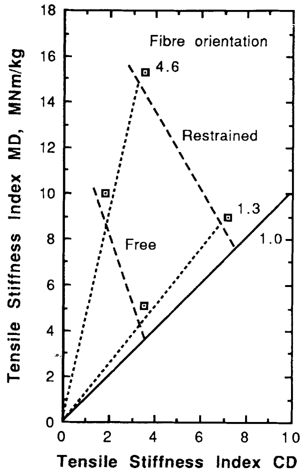


Figure 12 Tensile stiffness index, MD versus CD, for bleached sulphate papers 21 SR, for fibre orientations of 1.3 and 4.6. The sheets were dried either freely or under restraint, (11)

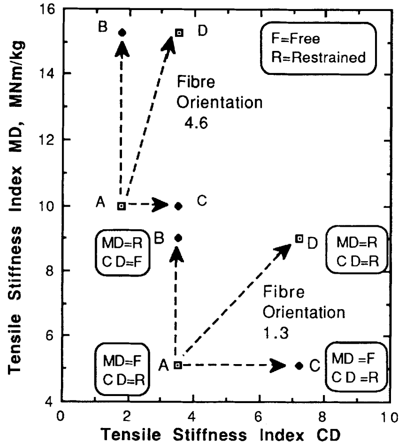


Figure 13 Tensile stiffness index in the MD versus that in the CD for the paper in Fig 12. MD and CD are subjected to different combinations of free and restrained drying, (11).

Fig. 12 shows the tensile stiffness index in the MD versus the tensile stiffness index in the CD for free or restrained drying with fibre orientations of 1.3 and 4.6. The solid lines indicate a fibre orientation of 1.0, i.e. an isotropic sheet with as many fibres oriented in the MD as in the CD. The sheet dried under restraint always has a greater tensile stiffness at a given fibre orientation than the freely dried sheet, both in the MD and the CD.

Fig. 13 shows the tensile stiffness index in the MD and CD for paper sheets with fibre orientations of 1.3 and 4.6 where the MD and the CD have been dried under different drying conditions. Point A shows the tensile stiffness index when both the directions have been dried freely. In point B, where the paper has been dried under MD restraint but still freely in the CD, the CD-value is unchanged while the MD-value increases markedly to the same level as that of the sheet dried under restraint in point D. This drying strategy agrees approximately with the situation in present-day cylinder dryers.

In point C the paper has been dried under CD restraint but freely in the MD. In this case, the MD-value is unchanged compared with point A, while the CD-value has increased to the same level as that of the sheet dried under restraint, point D.

The properties in the two directions can thus be affected completely independently of each other during the drying process.

In Figs. 14 and 15 the difference between free drying and drying under restraint is shown for the tensile index and compression index at two different fibre orientations. These properties can also be affected independently of each other in the two directions, (11).

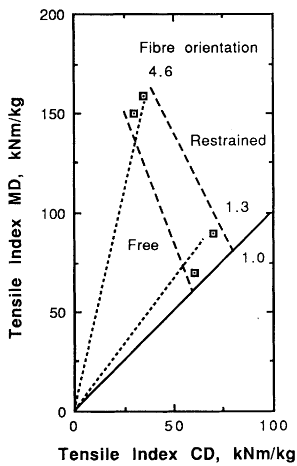


Figure 14 Tensile index in MD versus CD for the paper in fig. 12, (11)

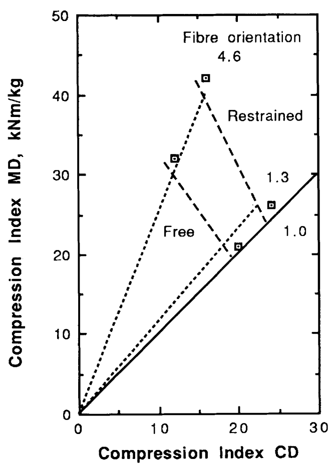


Figure 15 Compression index in MD versus CD for the paper in Fig. 12, (11)

To explain how the strength properties can be affected independently of each other during the drying, the paper can be imagined to be a fabric with curled fibres as is demonstrated in Fig. 16a. The fabric can be straightened out in the MD as in Fig. 16b, or in the CD as in Fig. 16c and in both directions as in Fig. 16d. It is obvious that the properties in the MD and CD in such a model can be affected independently of each other.

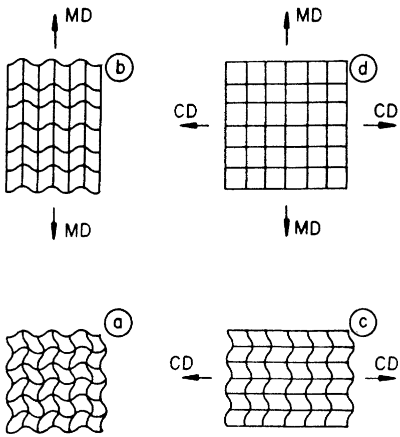


Figure 16 Schematic model where the MD and CD strength properties are changed independently.

DRYING STRATEGIES

Drying strategies - principles

Previous sections have shown how fibre orientation and drying conditions affect the mechanical properties of paper. This section shows the importance of drying strategies, i.e. shrinkage, drying under restraint or wet straining in a certain solids content interval, as a means of optimizing the end-use properties of the paper.

For each paper there is an optimum wet straining at a certain solids content which gives the finished paper its greatest strength and stiffness. The wet straining must in practice also be adapted to each type of paper, and taking into consideration, for instance, the danger of web breaks.

Wet straining - Restraint

In this section, the effects on the mechanical properties of paper of drying under restraint (no shrinkage permitted) and of wet straining (draw) of the web during drying are discussed. The sheet which has been dried under restraint throughout is regarded as the reference.

The strength and stiffness of paper can be increased by straining the wet sheet during the drying process, the extent to which they can be increased depending on the solids content at which the straining is carried out. Figure 17 shows the effect on mechanical properties achieved by a wet straining of 1 % versus the solids content at which the web was strained. A considerable increase in stiffness over that of the reference is obtained when a strain is applied at low solids contents. Similar results have been obtained for the tensile index and the compression index, (12).

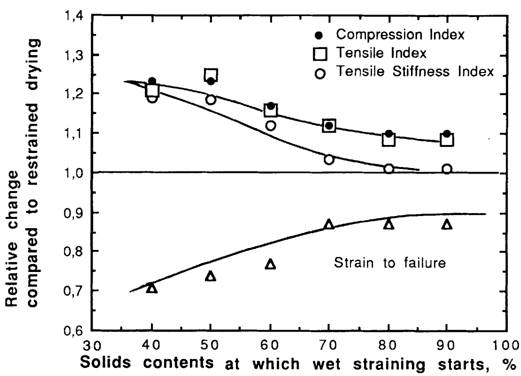


Figure 17 Relative change in properties compared to restrained drying for bleached sulphate papers 25 SR, subjected to 1 % wet straining at different solids contents. The sheets were restrained dried before and after the wet straining, (12).

In all cases, the effect on the mechanical properties is more marked when straining takes place while the web has a low solids content. This is to be expected considering the behaviour of paper during drying shown in Fig. 1.

Restraint - free

A test series was carried out with drying strategies involving different combinations of restrained and free drying in different solids content intervals, (12).

Fig. 18 shows the effects of different strategies on the tensile stiffness index plotted against the solids content and moisture ratio at which a change in conditions is made. The moisture ratio axis is linear and is proportional to the amount of water in the paper. For the curve Free + Restrained the sheet has been dried freely and then under restraint. The arrows in the figure indicate, as an example, how the curve can be used to show the tensile stiffness index when a change from free to restrained drying is made at a solids content of 60 %. For the curve Restrained + Free the sheet has first been dried under restraint and then dried freely. Both the curves are approximately linear, within the experimental accuracy. They are also the inverse of each other. The shrinkage plotted against the moisture ratio is highly non-linear. Small shrinkages at the beginning of the drying process thus have a large impact on the tensile stiffness index.

Htun and de Ruvo (13) suggest a superposition method to predict the mechanical properties in a case where the drying is alternated between free drying and drying under restraint a number of times. They demonstrated the method for predicting the strain to failure of paper made from chemical pulp.

The application of the method to the data given above for tensile stiffness index is shown in Fig. 19. In the period of drying under restraint, horizontal lines are followed and during free drying the sloping lines. If, for example, the paper is dried under restraint up to a certain moisture ratio C, freely to moisture regain D and again under restraint until the paper is completely dried, the final tensile stiffness index can be read at E.

The same tensile stiffness index would have been obtained if the paper had been dried freely to G, and under restraint until E.

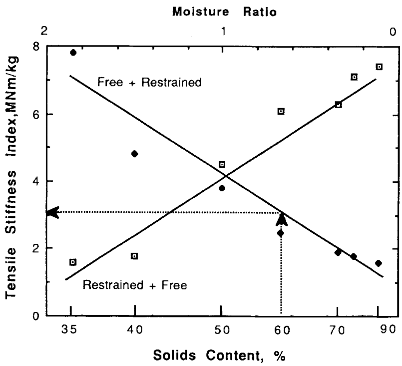


Figure 18 Tensile stiffness index versus the solids content and moisture ratio at which the drying conditions are changed. The Moisture ratio scale is linear. Isotropic bleached sulphate papers 22SR (12).

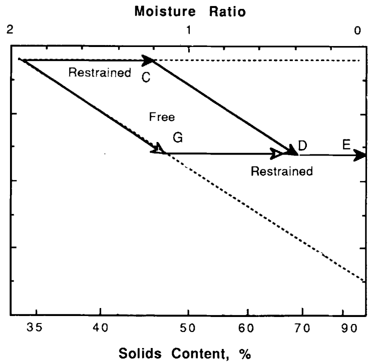


Figure 19 Principle for a superposition technique to predict the effect on tensile stiffness index depending on combinations of free and restrained drying. Data from Fig. 18.

The result of free drying or drying under restraint depends, according to this model, on the s i z e of the moisture ratio interval during which each type of drying takes place, and not on the part of the drying process in which it takes place. These results should be considered when drying sections for different products are designed.

In a pilot test it was found that it was more advantageous for the strain to failure and the tensile energy absorption in the CD for a kraft paper if it was dried freely up to 60 % solids content than to dry it freely after 60 %. This result is in qualitative agreement with the results in Fig.18, where it can be seen that about two thirds of the effect on the property takes place before 60 % solids content (14).

The tensile stiffness index has been calculated in Fig. 20 in a series model for a material composed of a stiff and a soft spring, (15).It is evident that the existence of only a few soft areas is sufficient drastically to reduce the total stiffness.

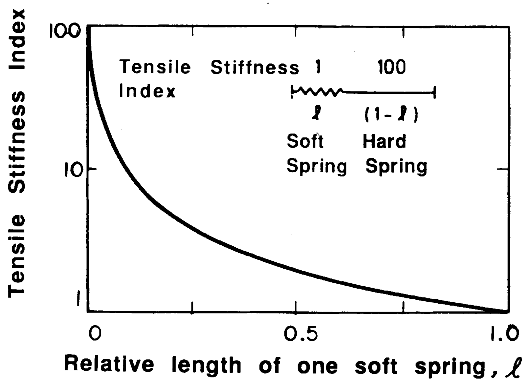


Figure 20 Model description of how the tensile stiffness index of paper depends on the relative lengths of a soft spring and a stiff spring, (15).

In the wet state the fibre wall components of the paper are soft and plastic. During drying the fibre shrinks, which causes the stiff and strong cellulose fibrils of the fibres gradually to deform. During extended free drying, these deformed zones gradually become visible in a microscope as micro-compressions. Applied to paper the above model says that these zones have a dramatic effect on the tensile stiffness index at low solids contents. By comparison, a larger deformation in a higher solids content interval has a much smaller effect. The model explains why even small shrinkages in the beginning of the drying have a large effect on the mechanical properties of the paper.

Wet straining - Restraint - Free

Fig. 21 summarizes another drying strategy trial for paper. Strategy No 5 means for instance that after wet pressing the sheet was wet strained 1 % at 40 % solids content and was then kept under restraint in this strained state until 70 % solids content, after which it was dried freely.

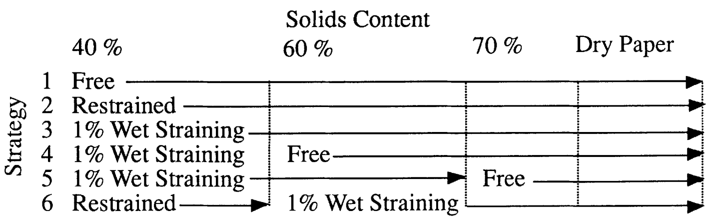


Figure 21 Drying strategies for bleached sulphate sheets (90 % softwood, 10 % hardwood) 20SR in CD.

Fig. 22 shows the effect of these different drying strategies on the mechanical properties of the paper. The properties of a freely dried sheet are chosen as reference. The sheet dried under restraint attains considerably higher values. A wet straining of 1 % at 40 % solids content gives a further considerable increase while a wet straining at 60 % solids content has a much smaller effect.

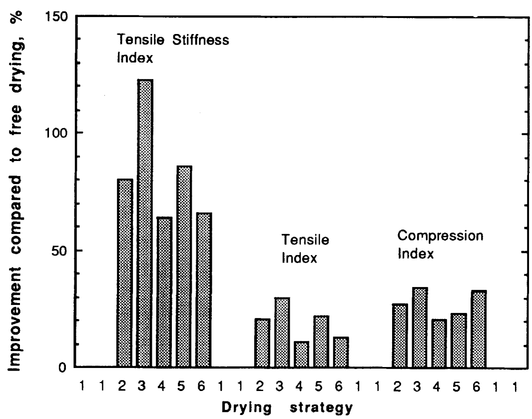


Figure 22 Improvement of properties compared to free drying for the sheets subjected to the drying strategies described in Fig. 21.

An application of earlier graphical interpolations is shown in Fig. 23 for tensile stiffness index where the reference state is 1 % wet straining at 40 % solids content and free drying. If the web is held in a strained position the line A - B is followed. If the sheet is dried freely the line A-C is followed. If wet straining takes place at 40 % and free drying after 60 % solids content the line A-D-E is followed. If free drying takes place after 70 % the line A-F-G is followed. The points H and I show experimental values. The agreement is good, which shows the technological potential for predicting effects of drying strategies.

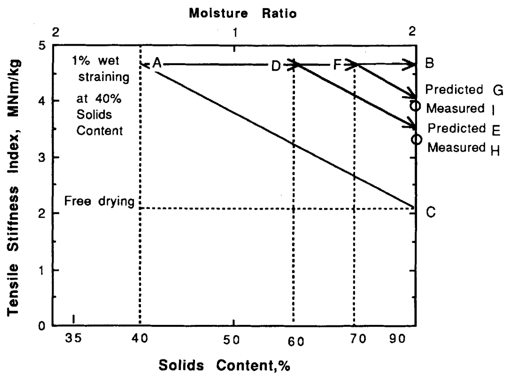


Figure 23 Linear superposition model for combinations of 1 % wet straining and free drying for tensile stiffness index versus linear moisture ratio. Comparisons are made between predicted and measured values for strategies 4 and 5 in Fig. 21.

Fig. 24 shows the drying force in the CD for strategies 2, 3 and 6. The drying force for drying under restraint follow the basic curves in Fig. 5. After a wet straining of 1 % the drying force increases instantaneously, after which it relaxes, depending on the viscoelastic properties of the paper. In the completely dried state the relaxation is negligible compared with the relaxation in lower solids content ranges.

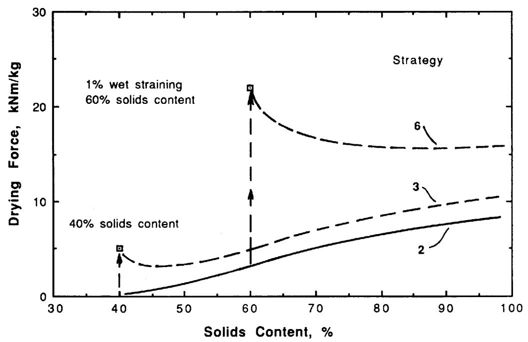


Figure 24 Drying force in CD versus solids content for strategies 2, 3 and 6 in Fig. 21.

A wet straining of 1 % at 40 % solids content gives only a marginal increase in the drying force compared with drying under restraint, but has a large influence on the mechanical properties, which is an advantage from the point of view of process technology in a paper machine.

Wet straining at 60 % solids content gives higher drying force but a smaller stiffness increase than a wet straining at a lower solids content.

The conclusion drawn from these measurements is that wet straining should take place as early as possible after pressing. This stretched state shall then be maintained as long as possible.

INVESTIGATIONS OF STRENGTH POTENTIAL IN A LINER BOARD MACHINE

The aim of the trial

Earlier laboratory tests have clearly shown the great influence which the drying conditions have on the mechanical properties of paper. A mill trial was therefore carried out with the intention of studying the variations across the web and assessing how well the strength potential of the paper is in reality utilized.

The trial was carried out on a modern liner board machine which was run on this occasion with a grammage of 150 g/m². Samples were taken after the second press and after drying.

Wet sheets were packed and transported to STFI to be dried in the laboratory. In order to attain the same density as after the third press in the machine, the wet sheets were pressed before drying to a density of 650 kg/m³ in STFI's laboratory press. The wet sheets were dried in the CD in the laboratory according to different drying strategies.

Results - machine dried sheets

The following figures show measured cross-direction profiles for mechanical properties relevant for liner board.

The profile across the machine of the strain to failure in the MD and CD is shown in Fig. 25. The MD-strain to failure profile is completely flat whereas the CD-profile is concave. Note that there is no general connection between MD and CD values.

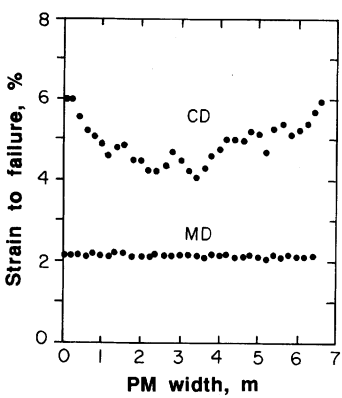


Fig 25

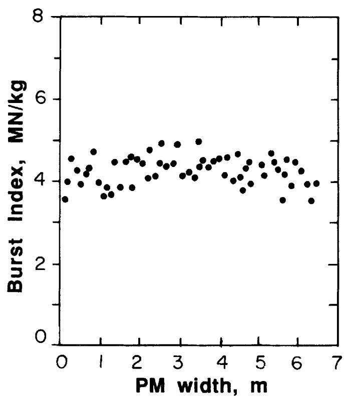


Fig 26

Figure 25 The strain-to-failure profile of a machine-made liner board paper.

Figure 26 Burst index profile for a machine-made liner board paper.

Strain to failure and shrinkage are clearly related, (12), and the shrinkage profile has a similar appearance.

The burst index, Fig. 26, shows a considerable scatter but the mean value is 10-15 % higher in the middle than in the edges.

Tensile stiffness index, tensile index and compression index, Fig. 27, show a flat profile for the MD-values while the CD-values are lowest at the edges. The middle of the web is approximatively 50 % stronger than the edge.

Study of the optimization of the strength potential of paper through laboratory drying

Wet sheets from the paper machine were pressed and dried in the laboratory with the drying strategies A-D, Table 1, in the CD. The results are presented in Fig. 27a. A comparison is also made in each diagram with corresponding values across the web for the machine dried papers.

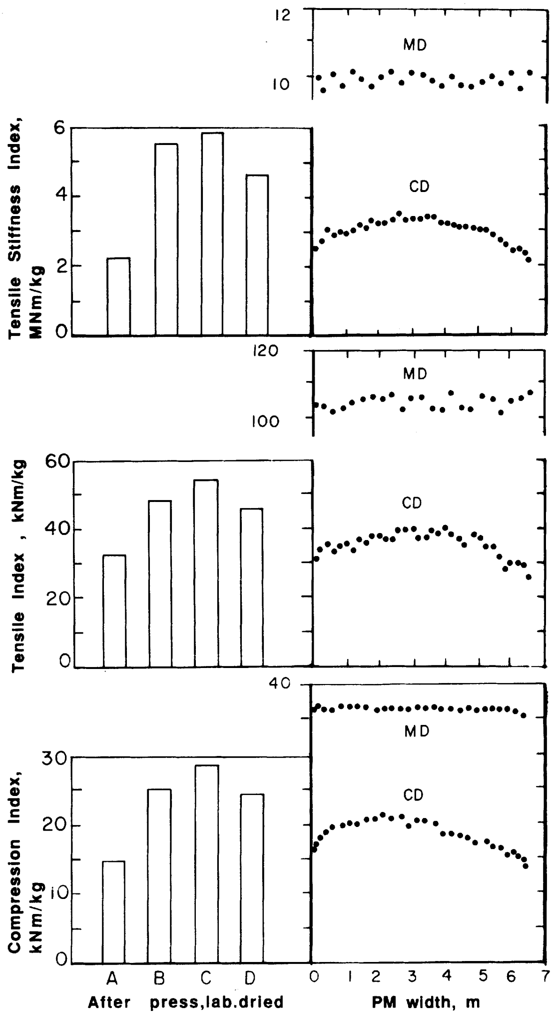


Figure 27 a) The effect of the drying strategies in table 1 on paper samples after pressing on the paper machine.
b) Property profiles for machine dried papers.

A. Free drying
B. Drying under restraint
C. 0.5 Wet straining at 40 % solids content, thereafter drying under restraint
D. 0.5 % wet straining at 40 % solids content, drying under restraint 40 - 75 % solids content, thereafter free drying

Table 1 Drying strategies for laboratory drying in the CD for machine made kraft liner

In general it can be said that the values attained by the edge samples are very close to those of sheets which have been dried freely in the laboratory, while the samples in the middle of the web have values which lie between those of freely dried sheets and sheets dried under restraint.

If the effects of the strategies A-D in table 1 are compared, it can be established that the advantage of the "optimum" strategy (C) compared with free drying (A), is a 162 % increase for tensile stiffnes index, 70 % for tensile index and 93 % for compression index. If the sheet is dried freely after 75 % solids content (D), a slightly smaller effect is obtained.

Compared with the middle of the machine the advantage of drying under restraint (B) is 63 % for tensile stiffness index, 27 % for tensile index and 23 % for compression index.

A NEW CD-RESTRAINING TECHNIQUE APPLIED ON A PAPER MACHINE

Earlier attempts to improve properties by preventing CD shrinkage

The realization that the mechanical properties of a certain paper are improved by preventing shrinkage has inspired many innovators to suggest processes for achieving this on the paper machine.

A large number of patents have consequently been granted over the years. A lateral wet straining of paper is achieved by the use of a stenter, where clips strain the paper, (16,17). Most of the patents involve more or less complicated devices. The most usual device involves rollers, with which the web is strained in the cross-direction at a certain position or at several positions in the machine. Examples of such rollers are given in references (18-21).

Investigations show that CD wet straining with expander rolls improves the dimensional stability (22).

The results so far presented in this article indicate however that in order fully to utilize the strength potential of the paper the web must be strained at a low solids content and be kept in a strained state over a large moisture content interval. The reason why rollers as a means of straining the web have had little effect on properties can be ascribed to the fact that they involve straining at discrete points.

THE CD RESTRAINING DEVICE

The patented CD restraining device (CDRD), developed by STFI and Fläkt Industri AB is a method for continuously preventing lateral shrinkage during drying. The device has produced paper with improved properties in a full-size paper machine.

The basic idea of the invention is that each edge of the paper web is glued to belts (Fig. 28) at the begining of the drying section. The belts are equipped with a guide edge, and they accompany the paper through a certain part of the dryer. The guide edge runs in tracks in the cylinder heads (Fig. 29).

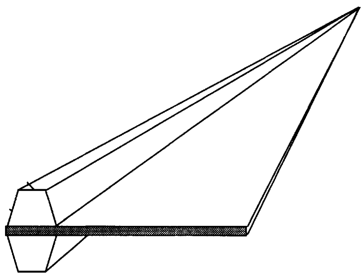


Fig 28

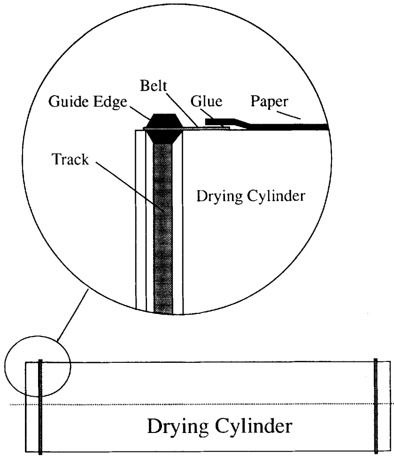


Fig 29

Figure 28 One of the two belts for the CD restraining system.

Figure 29 Schematic view of one cylinder with the belts placed in tracks. The papers are glued to the belts.

Fig. 30 shows a side view of the device. A water-soluble glue is applied to the belt by a spray in position B. By heating with IR in position C a suitable viscosity is obtained in the glue.

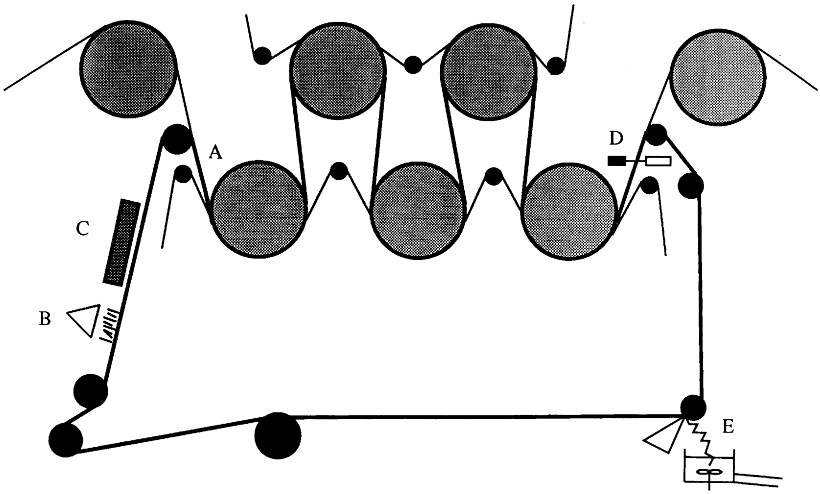


Figure 30 A side view of the CD restraining device.

The paper passes from the press section into a nip, A, between the belt and a drying cylinder where the paper is glued to the belt. The paper accompanies the belt through the dryer and is removed from the belt with a water knife at each edge at D. The belts are cleaned from paper by a water knife technique using fish tail nozzles in position E. The broke goes back to the process via a pulper.

Test parameters

After extensive laboratory tests, the new principle for preventing lateral shrinkage has been developed over a period of two years in a mill environment. The results of this first development phase, which was primarily directed towards the development of machine technology and towards runnability of the equipment, show that the equipment functions in a paper machine.

The effects on the properties of the paper were studied in connection with a final proof test of the equipment.

The unbleached sulphate pulp from recycled liner board had an average kappa number of 95 and an original beating degree of 17°SR. It was re-dried and slushed about 20 times without intermediate beating.

During the test, the belt was run through the electrically connected groups 2 - 5, which included cylinders 9 - 21. The belt was used in the solids content interval 52-83 %. Some important machine data are given below:

Forming unit	Fourdrinier
Press	1 double-felted and 1 single-felted
Machine speed	75 m/min
Wire width	4.9 m
Distance between belts	4.2 m
Number of drying cylinders	29 + Yankee between cylinders 21 and 22

Results

The paper technological evaluation of the equipment was carried out with these test parameters during a period of three hours.

The mean shrinkage of the 150 g/m² paper without the CDRD in the cross-direction was measured in the solids content range 52-83 % to be 2.1 %. This low shrinkage must be attributed to the fact that the pulp had been recycled so many times.

The strain to failure varies in the CD according to Fig. 31. Without CDRD, the paper shows a typical u-cross section, with the highest strain to failure at the edges. This profile reflects the shrinkage profile. With CDRD the profile is much better. The strain to failure is also lower. Measurements confirmed that when the CDRD-technique was used no shrinkage of the web took place.

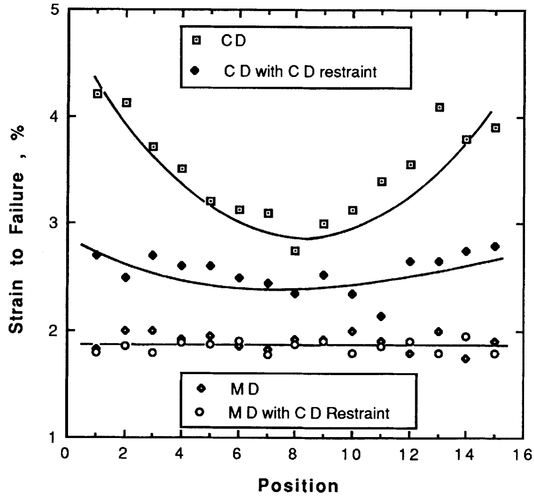


Figure 31 Strain-to-failure profiles with and without the CD Restraining Device (CDRD).

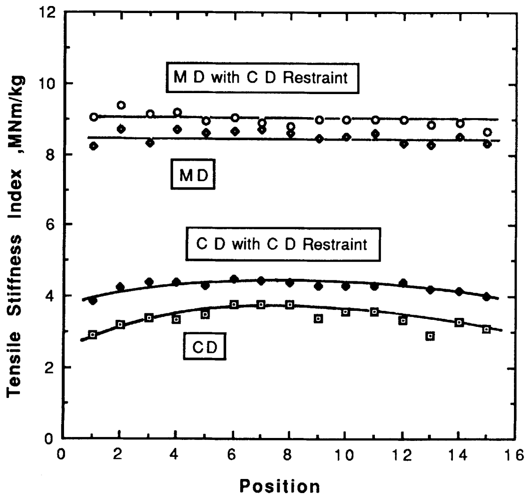


Figure 32 Tensile stiffness index profile for the CD Restraining Device (CDRD).

The MD-property profile is flat in both cases, and no great difference in level could be observed.

This prevention of shrinkage using the CDRD also affects the other properties. For the tensile stiffness index (Fig. 32), the coefficient of variation in the cross-direction was improved from 8.7 % to 5.5 % while the mean level increased 27 %. Although the MD-profiles were flat, it is worth noting that the MD-properties were also improved by CDRD. This can be attributed to an elastic interaction between the MD and CD (Poission's ratio).

An improvement was also obtained in the case of the tensile index and the compression index. (Fig. 33).

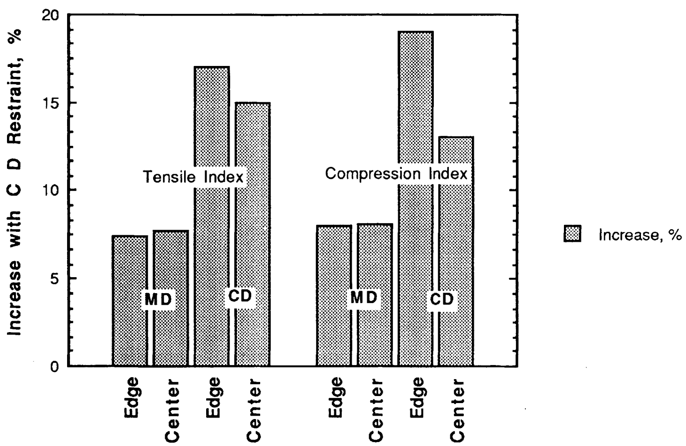


Figure 33 Relative increase in tensile and compression properties due to the CD Restraining Device (CDRD).

The conclusion drawn from these tests is that the device functions and that significant improvements in paper properties are obtained in an industrial environment. If the lower solids content had been displaced 5-10 percentage points towards the wetter region, larger effects would have been obtained. Larger effects would also have been obtained if a fresh and optimally beaten pulp had been used.

FINAL REMARKS

The laboratory results have shown that considerable strength and stiffness improvements in the cross-direction of the web can be attained if the shrinkage can be prevented or if the web can be strained in this direction. This improvement takes place without any deterioration of the properties in the machine direction.

A device has been tested which makes it possible to keep the paper under restraint in the cross-direction during drying in a full size machine.

It has then been confirmed that it is possible to improve the CD-property profiles without any deterioration in these properties in the MD. The properties in this direction have instead also been improved. The tests have qualitatively given the desired results, although the optimum conditions have not prevailed on the occasion of the trial.

The technique also has the potential of even being able not only to restrain but also to stretch the web in the CD, which would mean further improvements.

This invention has the potential of solving some old problems in papermaking such as evening out the cross-direction profile and improving strength and stiffness properties, dimensional stability and surface properties.

EXPERIMENTAL

*The laboratory sheetforming on the French sheetformer Formette Dynamique, the pressing and drying techniques of these sheets are described in references (13 and 23).

*The mechanical properties were evaluated according to SCAN-test methods. The tensile stiffness is evaluated from the maximum slope of the stress-strain curve in a tensile test.

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Transcription of Discussion

DRYING STRATEGIES AND A NEW RESTRAINT TECHNIQUE TO IMPROVE CROSS-DIRECTIONAL PROPERTIES OF PAPER

T. Hansson, C. Fellers and M. Htun

Dr. J. Colley, Associated Pulp & Paper Mills Australia

The grade of paper that comes to mind with this technique is copier paper which is 80 g/m^2 typically. One of the big difficulties in copier is getting uniform curl across the CD. So, the potential for this technique if you can get it to work at 750 m/min rather than 75 m/min is quite enormous. Have you considered using this type of grade?

T. Hansson

Yes curl would be less if one could dry the paper under restraint rather than freely in the cross direction. Furthermore I see no reason why the process would not work also at 750 m/min.

Prof. R.E. Mark ESPRI USA

Did I understand that you went up to 20 recycles?

T. Hansson

Yes

Prof. R.E. Mark

Do you have any figures for the change or stability for any of your mechanical properties over those cycles?

T. Hansson

No, we have not. In the laboratory we made free and restraint dried sheets and we found different results from those presented here.

Prof. R.E. Mark

You mean the difference between CD restrained and CD unrestrained?

T. Hansson

Yes, with and without. We found it decreased with the number of times we slushed it. The pulp degraded as we recycled it.

Mr. J.F. Waterhouse IPST USA

What was your dryness when you began the restraint in your experimental set up?

T. Hansson

52-83% solids content.

Mr. J.F. Waterhouse

I wish to make a further comment, I am sure we all realise this, but as we go to higher and higher dryness levels whether it be in conventional or extended nips or even impulse drying, then the restraint problem becomes greater in terms of both drying stresses and potential strength development. So if we were to dry a sheet say ultimately up to 80%, then it is even more important to be able to restrain the sheet at that level if we are going to fully realise the strength potential and .elastic properties of the sheet.

T. Hansson

I believe that the greatest advantage with this system is that the paper is restrained at lower solids contents. If the sheet is pressed to 80% solids there is only a small potential left with further restraining. Compared to impulse drying for example this system has the potential to also stretch the sheet in CD which would further increase the properties.