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# THE EFFECT OF CALENDERING AND SUPER-CALENDERING ON THE PROPERTIES OF SECONDARY FIBRES

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## 1—*Introduction*

IN general, only qualitative information is available concerning the mainly negative effect of the various processing stages of papermaking, after-processing and usage, on the recyclability and properties of wastepaper as a raw material for further paper making. However, it is quite unknown to what extent such negative influence is exerted by the various processing stages as, for instance, stock preparation, wet pressing, drying, calendering and supercalendering, printing, corrugating, and so on. In paper producing countries it is increasingly necessary to acquire knowledge about the effect of wastepaper recycling on the quality of the paper being produced, and this necessity increases with the higher proportion of wastepaper in the furnish as a whole. For this reason the Institute for Paper technology (Darmstadt) has for some time concerned itself with systematic investigations in the field of wastepaper usage. These investigations have so far been carried out by functionally converting virgin fibre half-stuffs into wastepaper by means of laboratory or semi-commercial scale simulation under controlled conditions, and then to note to what extent the type of fibre and the technical production conditions affect the properties of secondary fibres during repeated recycling.

Some of this work, for which there are so far no references in the literature, is described in the following sections, whereby the main emphasis is laid on answering the technologically interesting question—

What is the effect of finishing, i.e. calendering and supercalendering of wood free and wood-containing papers, on the quality and recyclability of the wastepaper?

Investigations to this end were carried out on commercial and semi-

*Under the chairmanship of M. I. MacLaurin*

TABLE 1—VARIABLES WHICH EXERT AN INFLUENCE DURING CALENDERING/SUPERCALENDERING ON THE LABORATORY CALENDER EXPERIMENTAL CONDITIONS, VARIED AND CONSTANT

| | *Papermaking influences* | | *Machine—technical influences* | | | |
|---|---|---|---|---|---|---|
| *Series of experiments* | *Type of fibre* | *°SR of the original furnish* | *Line pressure kN/m* | *Speed m/min* | *No. of nips* | *Roll-pairings* |
| 1 | varied[1] | constant[3] | 20–500 | constant[5] | 1 | steel/steel |
| 2 | constant[2] | 15–60 | 20–500 | constant | 1 | steel/steel |
| 3 | constant | constant | 20–500 | constant | 1 | steel/steel |
| 4 | constant | constant | constant[4] | 10–500 | 1 | steel/steel |
| 5 | constant | constant | constant | constant | 1–4 | steel/steel |
| 6 | constant | constant | 20–500 | constant | 1 | steel/paper |

[1] Bl. pine sulphate pulp, bl. spruce sulphite pulp, bl. birch sulphate pulp, mechanical pulp.
[2] Bl. pine sulphate pulp
[3] 40 °SR
[4] 100 kN/m
[5] 100 m/min

commercial scale plant. Both the furnish of the calendered papers and the operating conditions of the smoothness-producing units have been varied. The influence of these parameters on the stock and sheet properties of secondary fibre materials has thus been studied.

## 2—*Influencing and dependent parameters*

VARIOUS qualities of fibre were used in the furnishes. These were made into paper on a pilot machine and afterwards calendered/supercalendered under

TABLE 2—DEPENDENT VARIABLES DURING CALENDERING/SUPERCALENDERING ON THE LABORATORY CALENDER

| *Measured value* | | *Method of measurement* |
|---|---|---|
| *Paper properties* | | |
| Relative plastic compressibility | — | — |
| Apparent density | g/cm³ | DIN 53105 |
| *Fibre suspension properties* | | |
| Beating degree | °SR | ZM V/7/61 |
| WRV value | % | ZM IV/33/57 |
| Fibre length fractions | % | ZM VI/1/66 |
| *Laboratory handsheet properties* | | |
| Apparent density | g/cm³ | DIN 53105 |
| Air permeability (Bendtsen) | ml/min | ZM V/26/74 |
| Breaking length | km | DIN 53112 |
| Tear Strength (Brecht/Imset) | Nm/m | DIN 53115 |

DIN = (Deutsches Institut für Normung e.V.), German Standard
ZM = (ZELLCHEMING-Merkblatt), Recommended method issued by the Association of Pulp and Paper Chemists and Engineers, Germany

the operating conditions given in the Appendix and in Table 1. The objectives were the following—

(*a*) To note the paper, stock and handsheet properties which depend upon the influencing parameters stated in Table 1, when the paper was calendered/supercalendered on the laboratory calender. (The investigated properties are stated in Table 2.)

(*b*) The development of, and the relationship between, stock and handsheet properties. This had the aim to determine generally valid correlations, which would be largely independent of the kind of fibre and the operation-technical parameters.

## 3—*Results of experiments*

### 3.1—*Changes in waste paper/fibre properties, caused by calendering*

In calendering and supercalendering, the parameters of principal interest are line pressure, web speed and moisture content of the paper web, as well as the geometry and the properties of the roll material and the roll surface temperature.

3.1.1—*Line Pressure* To begin with, the development of paper, stock and handsheet properties will be discussed as functions of the line pressure applied during calendering. The relative plastic compressibility of the calendered papers was determined, as a measure of the stresses in the nip. Fig. 1 shows a semi-logarithmic plot where linear functions are obtained, confirming the results previously published by Baumgarten and Göttsching.[1] The increase of the compressibility is largely independent of the kind of fibre, even when the levels differ considerably. Although papers made from thick-walled Birch sulphate pulp exhibit only a relatively small plastic thickness reduction, in the case of mechanical pulp the somewhat loose web structure is considerably more compressed.

Among the stock properties the Schopper-Riegler value (°SR) shows varying trends for the different kinds of material. As may be seen in Fig. 2, the chemical pulps show a rise in °SR with rising line pressure; the mechanical pulps show a drop. In order to be able to interpret these differing trends, the development of the water retention value and the fibre length fractions has to be known.

Fig. 3 shows the decrease of the water retention value of the various secondary fibre stocks in relation to the rising line pressure. Starting from different levels, the water retention values (WRV) have decreased for every fibrous material. The mechanical forces in the nip have obviously caused fibre compressions which cannot be reversed when these fibres are dispersed in water; they then show themselves by a reduced swellability of the fibres.

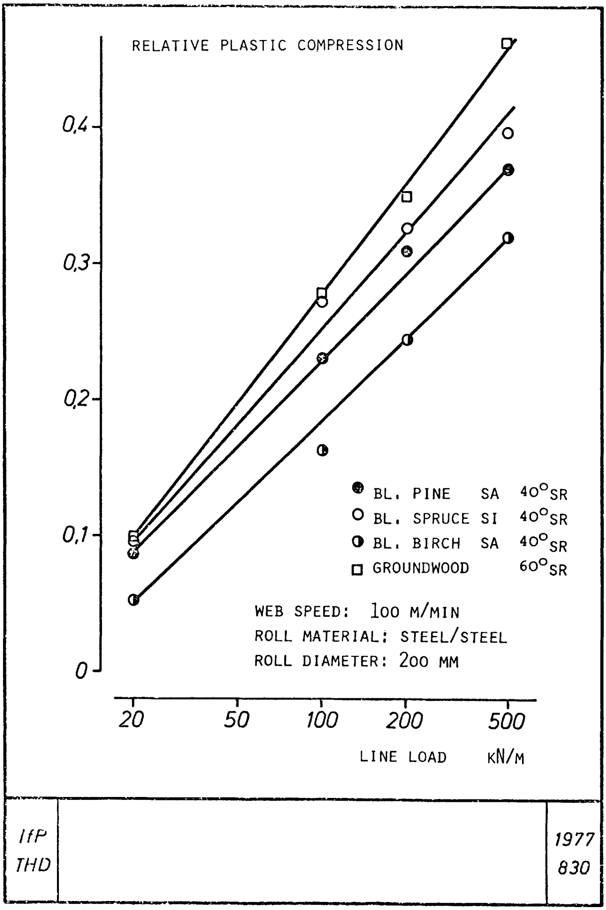


***Fig. 1***—Relative plastic compression for papers made of different pulps as a function of line load

Further, the forces in the nip have brought about fibre shortening and have thus altered the fibre length distribution of the pulp. Fig. 4 illustrates the relation between the long fibre content and the line pressure applied during the smoothing process. In the fibrous materials investigated, the long fibre content has been reduced by fibre shortening. Simultaneously, with increasing line pressure and lowered long fibre content, the percentage amount of short fibres and fines in the stock has increased.

The different trends for mechanical and chemical pulps during the development of the Schopper-Riegler (°SR) value (Fig. 2) can now be explained: The

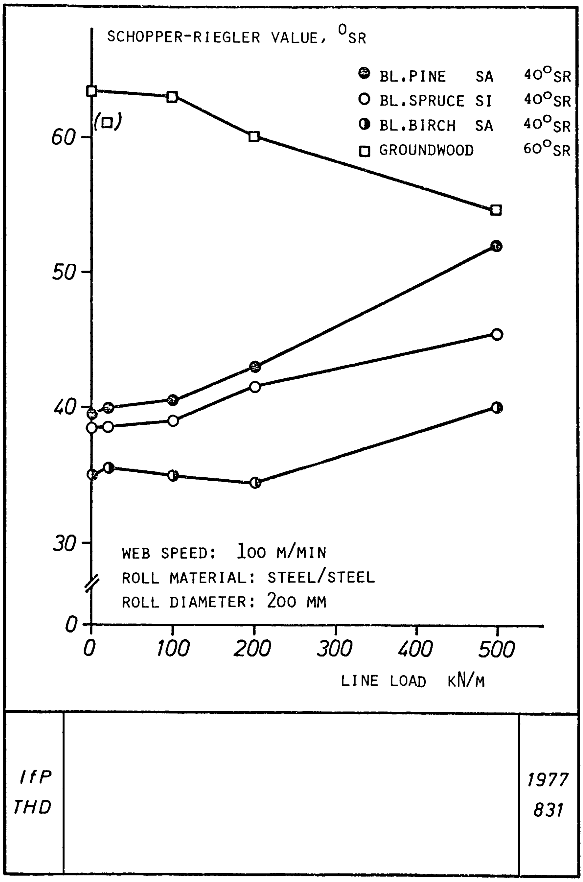


***Fig. 2***—Schopper-Riegler values of secondary fibre suspensions as a function of line load during the preceding treatment in the calender

lessening of the WRV values and the reduction of the long fibre content, caused by the fibre shortening, affects the Schopper-Riegler values in opposite ways. While a lessening of the WRV values produces, as a rule, a reduction of the Schopper-Riegler value, the opposite effect is caused by fibre shortening. For the fibrous materials here investigated, with the chemical pulps a fibre shortening invariably causes a rise in the Schopper-Riegler value. With mechanical pulp, which in any case does not contain many long fibres, the fibre shortening does not compensate for the decrease in the Schopper-Riegler value brought about by reductions in the WRV value.

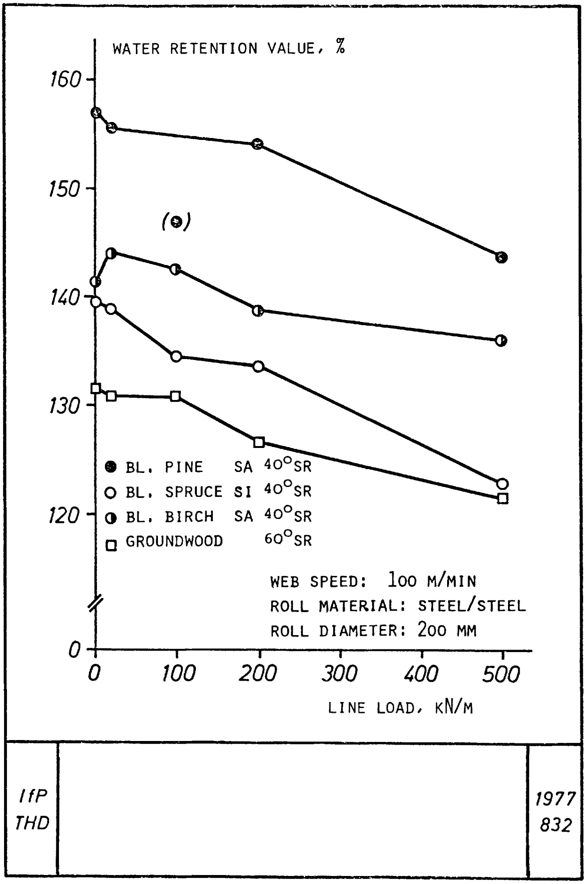


***Fig. 3***—Water retention value of secondary fibres as a function of line load during the preceding treatment in the calender

The breaking length is taken to represent the strength properties of handsheets, and is plotted on Fig. 5. Analogous to the WRV values, the level of these curves depends upon the kind of fibrous material and the curves also show a uniform reduction in the breaking length in response to the line pressure.

Finally, Fig. 6 shows that the tear strength of handsheets made from secondary fibres drops with increasing the line pressure used during the calendering of the preceding paper generation. The fibre shortening caused

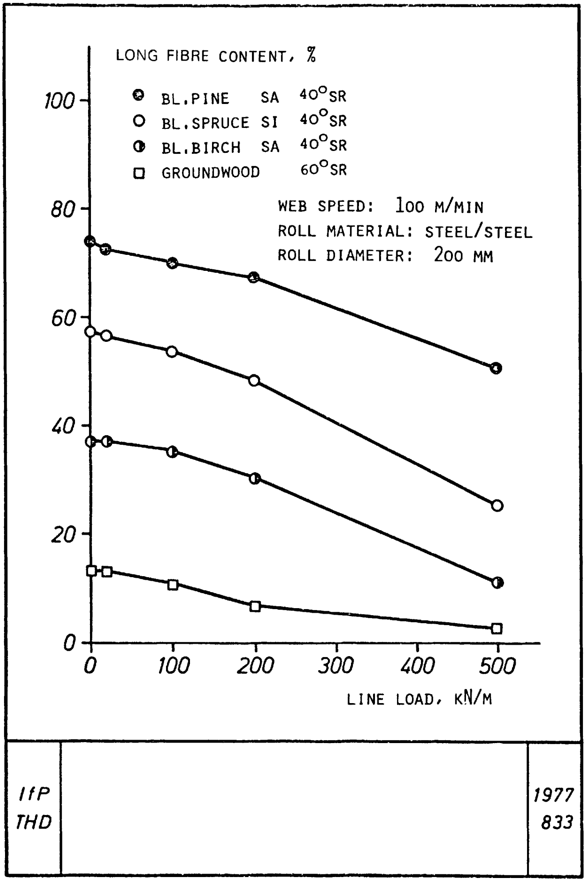


***Fig. 4***—Long fibre content of secondary fibre suspensions as a function of line load during the preceding treatment in the calender

by the calendering process therefore not only affects the properties of secondary fibre suspensions (by the creation of fines and the allied worsening of drainage rate), but the fibre shortening also causes a sustained negative influence on the tear property of papers made from secondary fibres.

The development of properties suggested the existence of certain analogies. These analogies, which could now be discerned between the water retention value and the breaking length, and also between the long fibre content and the tear strength, encouraged us to try to correlate the various stock suspension and

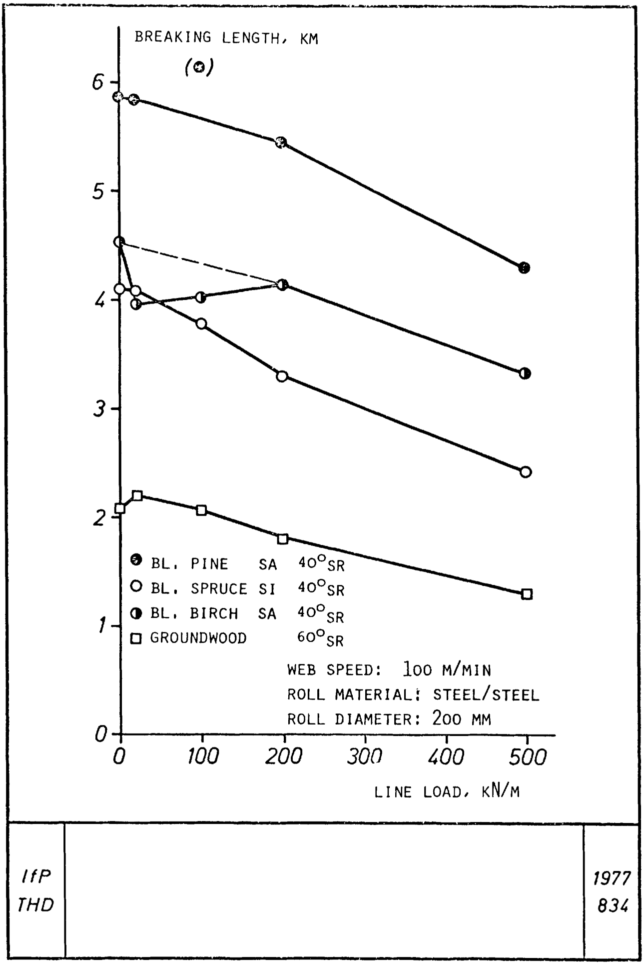


***Fig. 5***—Breaking length of handsheets made of secondary fibres as a function of line load during the preceding treatment in the calender

laboratory handsheet properties as noted in Table 2. In practical production, it is regrettable that the relatively simply-measured Schopper-Riegler value does not make a prediction of the strength properties (breaking length, tear) possible, because it is a complex measure and does not differentiate between different kinds of alterations in the material.

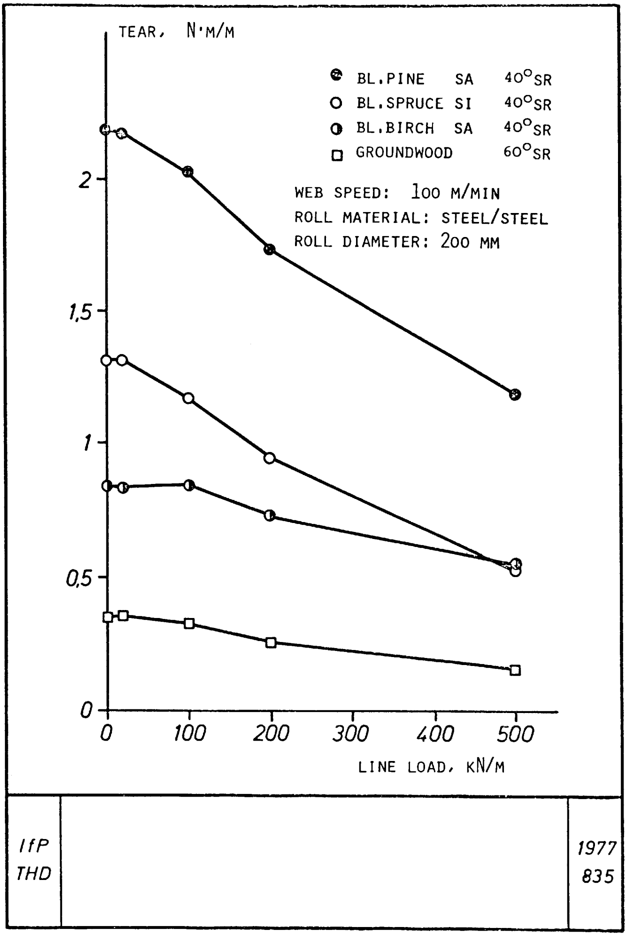


***Fig. 6***—Tear of handsheets made of secondary fibres as a function of line load during the preceding treatment in the calender

In contrast, the water-retention-value conveys considerably more information, as shown by Fig. 7. This value has a linear relation to breaking length, almost independent of the kind of pulp and of the operation-technical parameters during the calendering. The linear correlation of the WRV value and breaking length, within a certain range of beating degree, has been known for some considerable time from the researches of Jayme and co-workers.[2] What

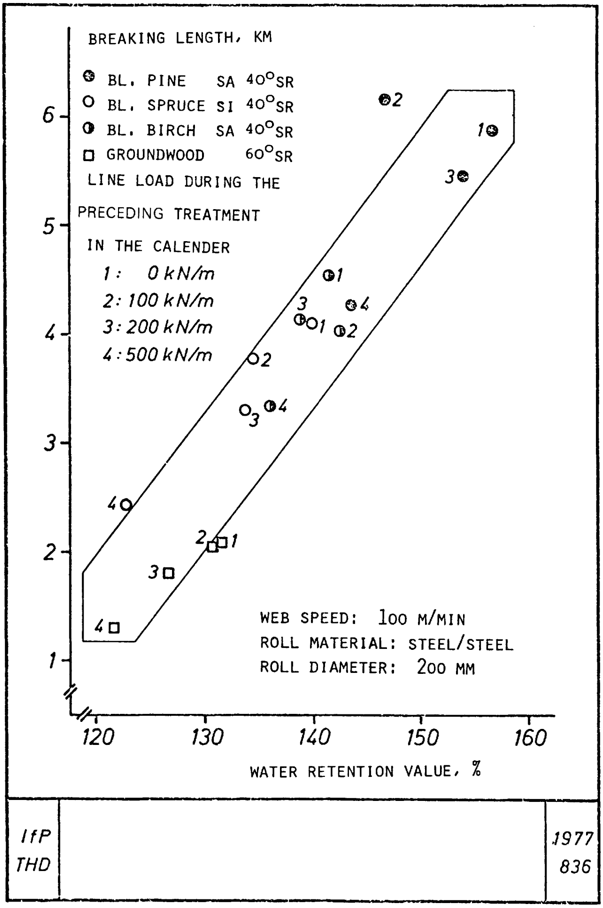


*Fig. 7*—Breaking length of handsheets as a function of the water retention value

is now new, is the finding that the WRV value can serve as an indicator for the development of breaking length, independent of the kind of pulp.

The relation shown in Fig. 8, between the long fibre content and the tear strength, is also of considerable practical value. Although a wide range of long fibre contents was covered, different pulps were used and various peripheral conditions employed during calendering. The measurements show only slight scatter about a connecting curve. It is thus possible to make generally valid predictions about tear strength on the basis of a determination of the long fibre content of a fibre suspension.

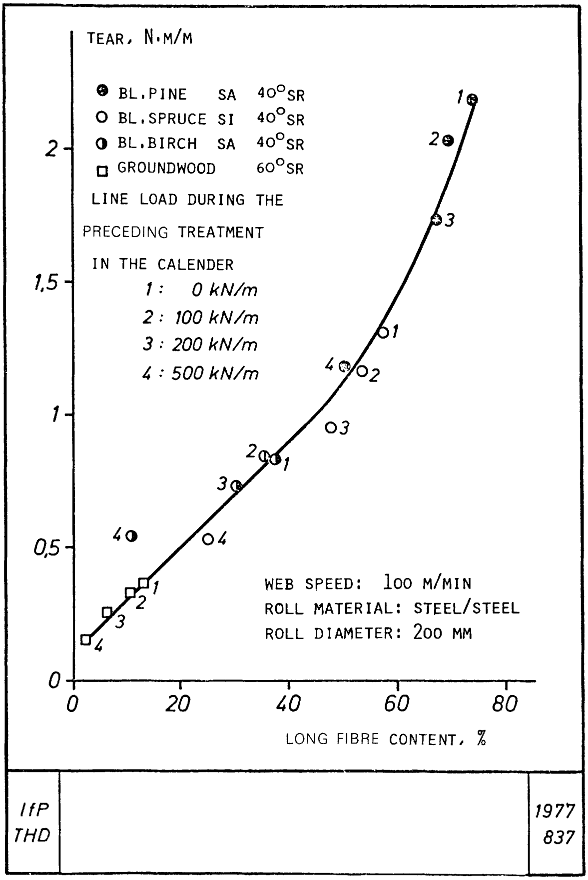


***Fig. 8***—Tear of handsheets as a function of the long fibre content

No doubt waste paper research is only at the beginning of this special field of regression analysis. With application of the knowledge developed by Forgacs[(3)] and Mannström[(4)] concerning the characterisation of mechanical pulps, the relations between suspension and sheet properties will probably be even better expressed and interpreted. However, this is unlikely to lead to a reduction in the effort expended in testing.

3.1.2—*Web speed during calendering* So far, the line pressure during calendering and its influence on the development of paper, stock and handsheet properties has been the subject under consideration. Attention will now be directed towards a further operational parameter—the web speed.

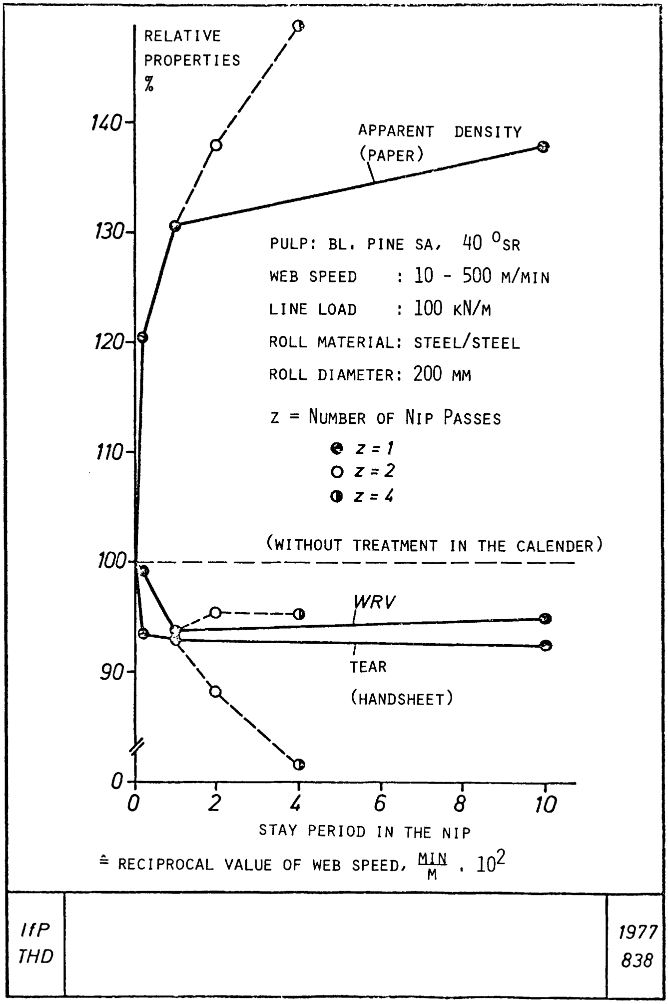


*Fig. 9*—Relative properties of paper, suspension and handsheets as a function of the stay period in the calender nip

In Fig. 9 the properties of paper, stock and laboratory handsheets are plotted as relative characteristic numbers (uncalendered sample = 100 per cent), in relation to the reciprocal value of the web speed. The calculated reciprocal values of the web speed are proportional to the dwell time in the

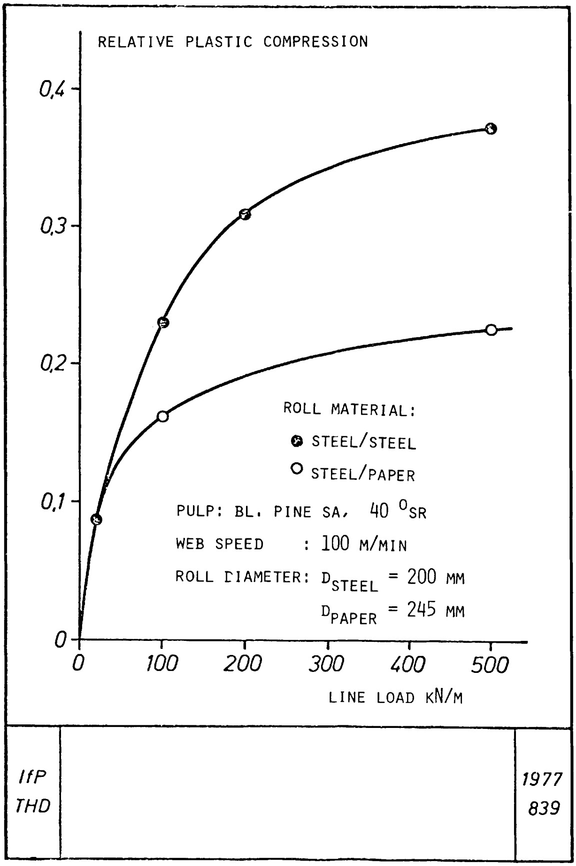


***Fig. 10***—Relative plastic compression of papers treated between rolls of different materials as a function of line load

nip during calendering. The type of pulp and the line pressure were kept constant.

The density increases with increasing dwell time in the nip, although the main increase occurs already during brief dwell times at high machine speeds.

In place of other stock (suspension) and handsheet properties, the water retention value and the tear are also shown on the diagram, as they were developed.

3.1.3—*Roll material* In all investigations up to now, the paper has been stressed by normal forces between two steel rolls. Because of the fundamental importance of the actual pressure per unit area in the nip—mainly concerning the reduction of paper thickness and the properties of the fibre suspension and of the handsheets—the roll combination was varied. By pairing a steel roll with a paper bowl the influence of supercalendering was simulated.

For both the roll pairings used to test the effect of treatment in the nip, Fig. 10 gives again the plastic compressibility as it depends upon the line pressure. It can clearly be discerned that the paper becomes considerably less compacted between a steel roll and a paper bowl than between two steel rolls. Because of the elasticity of the paper bowl, the nip width at the same line pressure becomes larger than with the steel/steel roll pairing.

With the roll pairing steel/paper, fibre damage in the web was not noted—even at high line pressures: In consequence of the reduced pressure per unit area in the nip, the properties of fibre suspension and paper remained unaltered compared with the uncalendered sample material. In particular, there was no reduction in the long fibre content with consequent reduction in tear strength, although the web speed, at 100 m/min., was on the low side compared with commercial practice.

3.1.4—*Number of nip-passes* On industrial calenders, the paper web frequently passes not just through one, but through a series of nips of a multiroll calender. In order to investigate the influence of multiple pressing on paper, stock and handsheet properties, sample strips were repeatedly passed through the laboratory calender, whereby other furnish and machine-technical conditions were kept constant. Fig. 9 shows the development of some properties, as related to the dwell time in the nip. An increasing number of nip-passes (i.e. prolonged dwell time in the nips) results in an almost linear increase of the density of the paper. However, the water retention value of the disintegrated paper (i.e. the suspension of secondary fibres) remains at the same level from two to four passes through the nip. Although it was only possible to prove a reduction in the long fibre content after the first nip, the tear strength of the handsheets made from secondary fibres reduces with an increased number of nip passes.

### 3.2—*Property changes related to paper-technological parameters*

3.2.1—*Influence of the Schopper-Riegler value of the fibre furnish* The influence of the type of pulp forming the furnish has already been dealt with in connection with the investigation of machine-technical variables. The Schopper-Riegler value (°SR) will now form the main subject under consideration. Fig. 11 shows the changes of the relative plastic compressibility for four different line pressures and depending upon the °SR of the fibre furnish. A lessening of the plastic thickness reduction with increasing °SR of the furnish

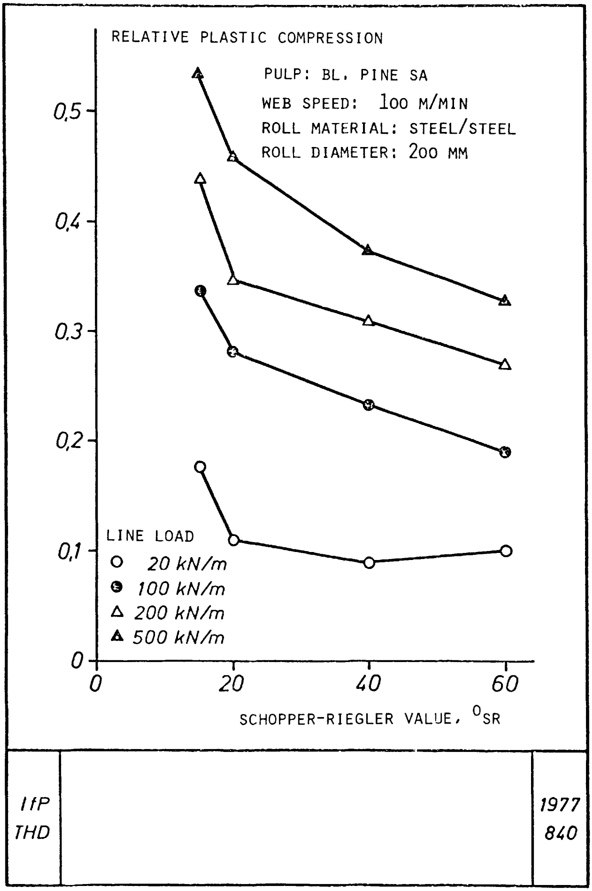


***Fig. 11***—Relative plastic compression for different line loads during the preceding treatment in the calender as a function of the original °SR value

occurs at all line pressures. Papers made from stock with high °SR have a greater density than types of paper made from less beaten stuff; even before calendering. As expected, however, a dense paper shows considerably less thickness reduction during calendering than does a bulky paper.

Fig. 12 is intended to provide an answer to the question, whether the °SR of a paper furnish affects the downgrading of the secondary fibre qualities of a paper, insofar as this downgrading is effected by the calendering. To this end,

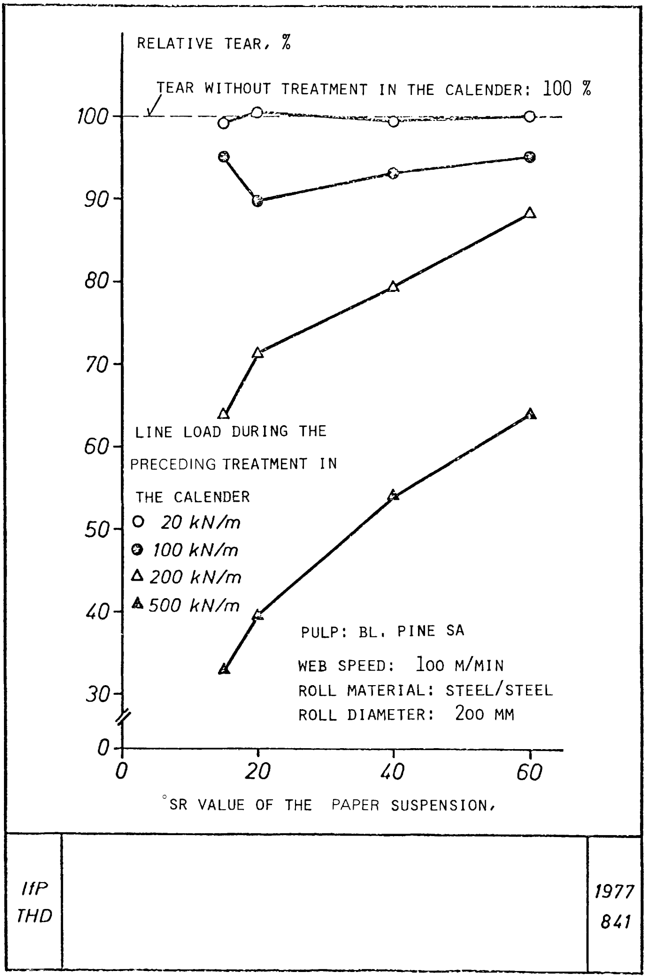


***Fig. 12***—Relative tear of handsheets made of secondary fibres, treated in the calender as a function of the original °SR value

use has been made of the tear strength, which responds very sensitively to mechanical fibre damage. The relative measured values, plotted along the ordinate of the figure, relate to the tear strength of laboratory handsheets made from uncalendered sample strips (see Appendix). The 100 per cent line thus corresponds to 'zero' line pressure. For a further four line pressures, and in dependence upon the °SR of the fibre furnish for the virgin paper, the diagram illustrates the extent of the reductions of the relative tear strength for laboratory handsheets made from calendered secondary fibre stock.

At line pressures of 20 and 100 kN/m, the relative tear strength remains unchanged or is only slightly reduced. The tear is definitely reduced at the larger mechanical calendering stresses of 200 and 500 kN/m. The extent of this reduction at these line pressures is clearly dependent upon the °SR of the stock from which the first paper was made. When the °SR was low, the stresses in the nip cause an enormous drop in the relative work-in-tear. With rising degrees of beating, the drop in strength becomes less, until, at 60 °SR, the strength reduction is only about half of that occurring in the case of an unbeaten original paper furnish. Furnishes, which are only slightly beaten, thus suffer particularly severe strength reductions through mechanical fibre damage. However, this statement should not be interpreted to mean that heavily-beaten fibres are better than lightly-beaten furnishes in respect of their re-use potential. As has been shown in previous investigations, lightly-beaten fibres are less affected by drying than heavily-beaten fibres in respect of their bonding ability. This positive effect, concerning their re-use quality as secondary fibres, is likely to more than compensate for the disadvantageous sensitivity to the effect of calendering.

3.2.2—*Influence of the moisture in the paper* In order to elucidate to what extent the sensitivity to calendering effects depends upon the moisture content of the calendered papers, the sample strips were conditioned for 24 hours prior to calendering at various relative humidities. At a constant temperature of 20° C, relative humidities of 0, 65 and 100 per cent were selected. It can be seen from the data plotted on Fig. 13, based upon the uncalendered sample strips, that the relative values for the apparent density of the papers increase with increasing humidity of the air; however, the relative values of the °SR and the WRV of the fibre suspensions made from these stressed papers decline slightly with increasing humidity. The measured values of the long fibre content, the tear and the breaking length are largely independent of the relative humidity during calendering (i.e. they are not affected by the moisture in the paper).

## 4—*Conclusion*

MECHANICAL stressing of paper between steel rolls causes severe worsening of the stock and handsheet properties of the 'waste paper' with increasing line pressures. The normal forces in the nip act destructively upon the fibre structure and they also diminish the swellability of the fibres, as indicated by their water retention value. This results in reductions in the strength properties, such as breaking length and tear. The properties of the fibre suspension and

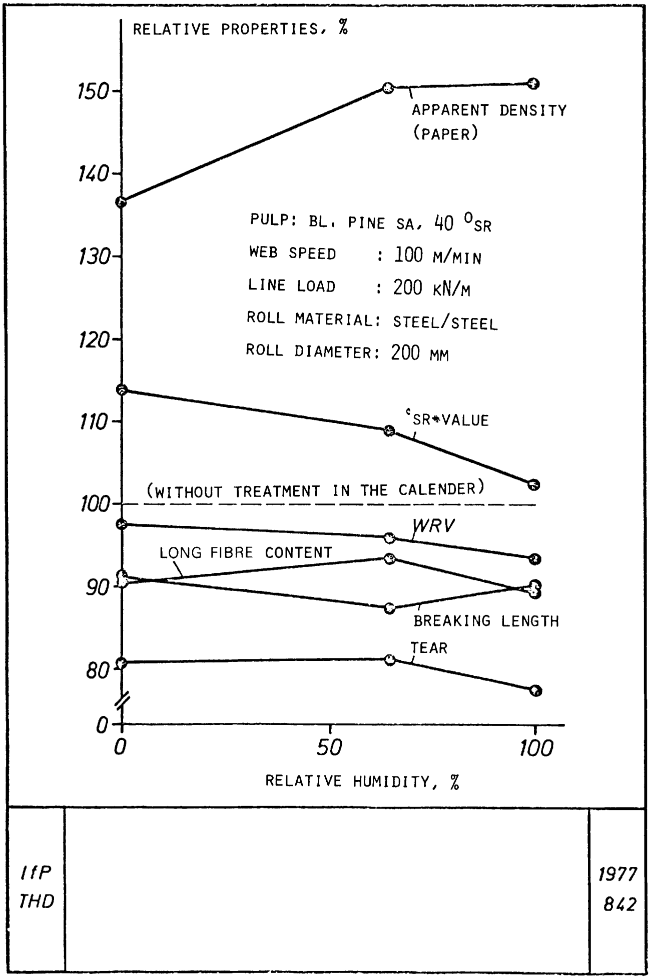


***Fig. 13***—Relative paper, suspension and handsheet properties as a function of the relative humidity during conditioning the paper web before the treatment in the calender

the strength properties are correlated, and these correlations are largely independent of the type of fibre and the conditions applying during the calendering process. On the other hand, stressing the paper in the nip between a steel roll and a paper bowl results in a considerably smaller reduction of the fibre suspension and handsheet properties of the ‘waste paper’.

Finally, papers made from lightly-beaten furnishes are subject to more severe irreversible changes than are heavily-beaten papers. However, it should not be forgotten that, in consequence of the drying of paper, the fibre-to-fibre bonding ability of heavily-beaten fibres is the more severely affected.

## Appendix

*Experimental conditions*

1—*Furnishes*

Bleached chemical pulps and one mechanical pulp; all supplied pre-dried at about 90 per cent dryness.

softwood sulphate (Pine)
hardwood sulphate (Birch)
softwood sulphite (Spruce)
softwood mechanical (Spruce)

2—*Beating*

The pulps were beaten to 40° SR prior to papermaking in the Voith Overthrow Hollander, at 6 per cent consistency (charge 1 500 g over dry). The pine sulphate pulp was also beaten to various °SR (unbeaten, 20° and 60 °SR). The mechanical pulp was disintegrated, but not further beaten.

3—*Papermaking*

The beaten or disintegrated fibre suspensions were diluted to 1 per cent consistency with fresh water in the machine chest. The paper was made on the Kämmerer paper machine from the various furnishes at the following operating conditions:

| | |
|---|---|
| machine speed | 1·1 m/min |
| web width on the wire | 240 mm |
| grammage | 80 g/m$^2$ |

4—*Calendering of the papers*

With the aid of a slitter and a cross cutter the papers were cut into strips (500 mm length × 50 mm width). The conditioned strips were fed into the nip of a laboratory calender and calendered at the following operating conditions:

| | |
|---|---|
| Roll diameter | 200 mm (steel); 245 (paper) |
| Roll pairing | steel/steel; steel/paper |
| Line pressure | 20–500 kN/m |
| Speed | 10–500 m/min |
| No. of passes | 1–4 |
| Air r.h. | 0–100 per cent |

5—*Testing*

5.1—*Paper properties* The mass per unit area and the thickness of the paper strips was determined before and after calendering, so that the apparent density could be calculated according to DIN 53105.

5.2—*Properties of the fibre suspension* Before and after calendering, paper strips were disintegrated in the laboratory disintegrator according to the method given in ZELLCHEMING-Merkblatt V/4/61, and the properties of the suspension given in Table 2 were determined.

5.3—*Properties of the laboratory handsheets* The fibre suspensions, made according to section 5.2, were used to form handsheets on the Rapid-Köthen sheet former in accordance with ZELLCHEMING-Merkblatt V/8/57, and these handsheets were tested for the properties given in Table 2.

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# Transcription of Discussion

## *Discussion*

*Mr I. K. Kartovaara* You have used two parameters to describe the calendering: Linear pressure and plastic deformation. Now we heard a paper at the 1973 conference, I think by a Canadian gentleman, about the effect of calendering on the strength properties of newsprint and I think he showed very clearly that the critical parameter, as far as the loss of strength is concerned, is the density of the paper web at the point of maximum compression in the calender stack and that when this maximum compression is approaching the density of the fibre wall we get very bad damage and a great loss of strength. So I think that the better criterion to look at is not the linear pressure or plastic deformation. It must be the density of the paper web at the point of maximum compression.

*Göttsching* Yes, I would like to agree with your ideas, but we have to sell our results to the people in the production units and therefore we need for didactic reasons the conventional parameters. But, on the other hand, it is too poor a parameter to describe the effects and it is better to relate them to plastic compression. But I am not familiar with how to measure and reproduce the density at the point of the maximum load.

*Mr S. Okushima* Calendering of newsprint can cause morphological changes of the fibre wall. Did you observe such changes by calendering in the case of recycling?

*Göttsching* We have not proceeded far enough to be able to describe morphological changes. We have so far only considered the results of fibre fractionation but we will also look at morphological changes.

*Under the chairmanship of M. I. MacLaurin*