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VISCO-ELASTIC PROPERTIES OF WET WEBS UNDER DYNAMIC CONDITIONS

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ABSTRACT

The forming of the web in a paper machine is a highly dynamic process in which the dynamic mechanical properties of the web in the x, y and z directions are each of central importance for both the process operation and the properties of the final product. The properties in the x and y directions, such as the dynamic tensile stiffness and stress relaxation, affect control of the draw in open draws, web flutter and stress variation. The dynamic mechanical properties in the z direction affect the behaviour of the web in the press section and the post-press dry solids content. All these features are also related to the properties of the final product.

Laboratory research on the dynamic mechanical behaviour of wet webs has been carried out with special equipment designed to simulate the paper production process, particularly its dynamic characteristics. The draw and press simulators have been built to monitor and handle properties related to the dynamic mechanical behaviour of paper. The draw simulator has been used to study dynamic tensile stiffness and visco-elastic component of the web during drying. The press simulator has been used to monitor the compressibility and pressure in the web as a function of different press impulses and wet pressing temperature.

INTRODUCTION

The output rate of a paper machine in general, and in particular in the case of newsprint, is most heavily dependent on the visco-elastic properties of the wet web under dynamic conditions. Web duration in the wire section of a newsprint machine is about 1000 msec, in the open draws between drying cylinders about 100 msec, in open draws between the press and drier section say 10 to 20 msec, and in the press nips 1 to

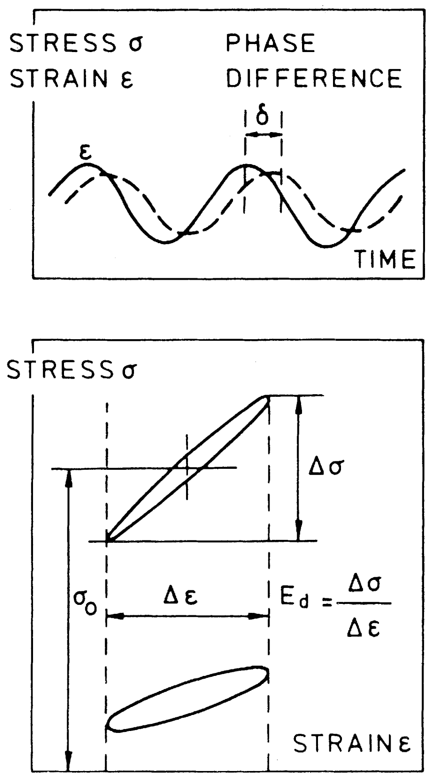

Fig 1—Principle of the dynamic elasticity and visco-elasticity measurement in time-base and in a stress-strain diagram.

3 msec. Further time factors include cyclic load disturbances such as web flutter in the open draws, the cycle length of which is in the order of 100 to 500 msec (1), and the frequencies of roll and cylinder rotation, the cycle lengths of which vary from 50 to 300 msec. In other words, when discussing the dynamic phenomena that affect the web in a paper machine, we are talking in terms of milliseconds, 10 to 500 msec for lateral loads and a few milliseconds for z-directional loads.

It is therefore obvious that for the study of factors affecting the runability of the paper machine, such as web breaks, flutter, wrinkling and the wet press dewatering capacity, we explicitly need to know the web behaviour under dynamic load conditions, and consequently the measuring methods as well as the capacity of measuring equipment have to meet these requirements.

In our present research work, a great deal of attention was paid to the measuring methods for predicting the web's mechanical behaviour - by which we mean in-plane stress relaxation and dynamic viscoelasticity and z-directional dynamic compressibility - under the load conditions specified above. For the purposes of the study, we designed and constructed an apparatus for simulating the individual processes in a paper machine, such as wet pressing and open web draws.

THE MEASURING METHODS

Owing to the dynamic nature of the phenomena to be determined, it was necessary to desig special measuring devices with sufficient capacity to simulate the loads and load variations on the paper web and to measure, with greatest possible accuracy, web deformation as a function of time.

Measurements in the in-plane direction of the paper

Determination of the stress relaxation

The stress relaxation is in principle measured on a paper sample by introducing into it a specified strain which is then considered as a constant when measuring the stress relaxation as a function of time.

The relaxation of stress takes place at such a speed that part of the tension may become relaxed as the stress is increased. Therefore, the stress rise-time should not exceed the time constant of relaxation (2). The measurements were partly carried out on an Instron tensile tester and partly on a dynamic material tester built at FPPRI. With Instron, the rise-times even at best are a little too long at around 100 msec. The dynamic material tester allows rise-times of about 10 msec, which is enough for testing the paper.

The device can also be used to study the stress relaxation behaviour of the sample by gradually increasing the stress on the sample at regular time intervals and monitoring the development of stress as a function of time. Thus the relaxation speed of the stress in the sample can be determined as a function of both stress and strain.

The measurement of the dynamic tensile stiffness and its visco-elastic component

The principle of the method is shown in Fig.1. Sine-shaped stress variation - in which frequency and amplitude can be varied - is introduced into the prestressed sample. As a result, diagonally elliptical hysteresis-loops are formed on the stress - strain diagram and the dynamic tensile stiffness E_d of the sample can be derived from their inclination. From the phase-difference between the stress and strain signals, it is possible to calculate the loss-factor, $\tan\delta$, which illustrates the visco-elasticity of the material (3),(4). The loss-factor is the relation of stored energy to the energy lost through internal friction.

In practice, the measurement is carried out as follows: the sample is first loosely clamped, after which the lower jaw is caused to oscillate at a desired frequency and amplitude. Next, the sample is strained to the point, where the elastic stress barely exceeds the amplitude of oscillation. Now it is possible to monitor the state of the sample, as its dry solids content and temperature, or both, change in a controlled manner. When using higher oscillation amplitudes, the stress on the sample has to be gradually increased throughout the measurement to maintain a slightly higher elastic strain component in relation to the oscillation amplitude to keep the sample tight throughout the oscillation cycle. Thereby, it is

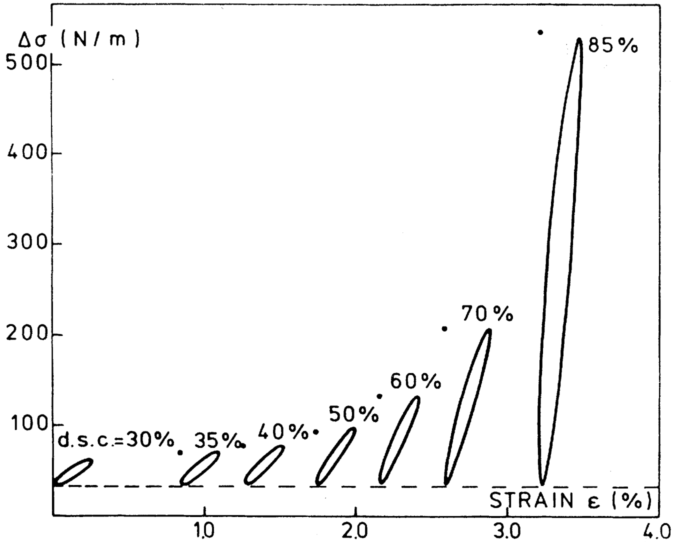

Fig 2—Stress-strain behaviour of the sample during dynamic tensile load cycling measurement as a function of increasing dry solids content (d.s.c.).

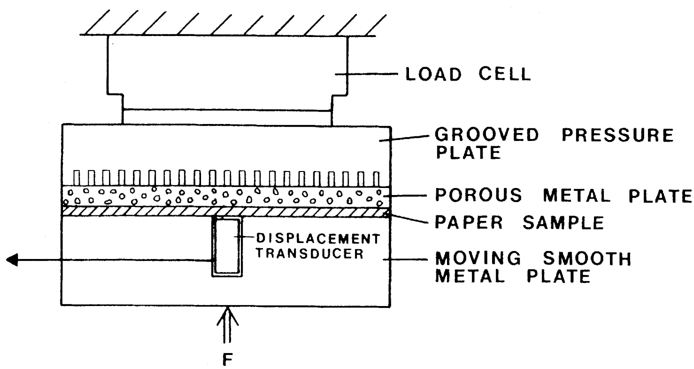

Fig 3—The compression plates used in dynamic compressibility measurements.

also possible to obtain information on the development of the plastic strain ε_p in the sample as a function of the dry solids content. Fig.2 shows an example of this mode of determination. With lower amplitudes, no extra stretching during the test is required and the test can be carried out on a standard length of sample.

Equipment

The sample is fitted between paper clamps. The lower clamp jaw is fixed to an electro-magnetic vibrator to produce the required stress and stress variation in the sample. When using sine-shaped stress variation, the amplitude of movement can be changed within the range 0 to 6 mm and the frequency between 5 and 1000 Hz depending on the amplitude. The equipment also includes either a piezoelectric or strain-gauge stress transducer with amplifiers. These serve to monitor the development of tension in the sample as a function of time. The equipment further includes a control unit to maintain the pre-set strain amplitude at varying load and frequency and to perform measurements at an evenly changing frequency. The results are stored on a 2-channel transient recorder and further to the plotter and desk computer. When necessary, the oscilloscope can also be used as a monitor during testing.

The measuring chamber is air conditioned and the temperature can be varied between 23°C and 100°C and the humidity between 30 % and 100 % depending on the temperature. The air conditioning is based on the circulation and mixing of air and on an insulated mixing chamber, where the temperature is regulated by a 600 W resistor element and where humidity is produced by valve-operated short water vapour impulses directed at the resistor. For measurements at room temperature, the required humidity can be maintained with greater accuracy by using a mixture of water and glycerol.

Measurements in the z direction

The aim of measurements of web compressibility in the z direction is to study the dynamic visco-elastic and plastic web properties under conditions corresponding to the wet pressing process in papermaking. The results also provide data on the dewatering efficiency in different wet press concepts.

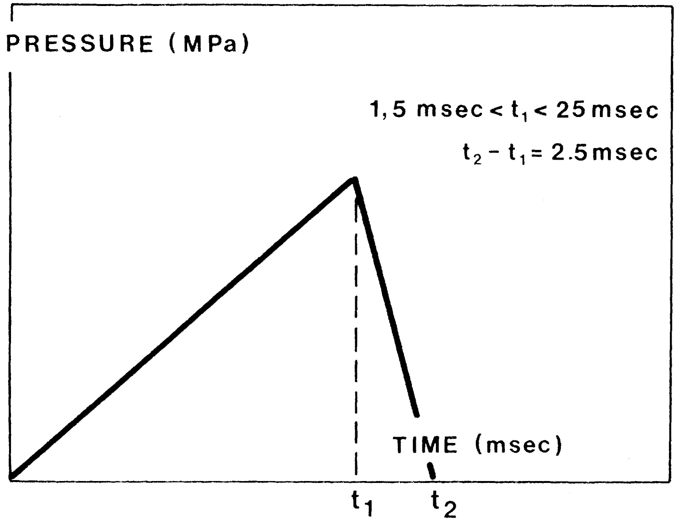

Fig 4—The pressure impulses used in dynamic compressibility measurements.

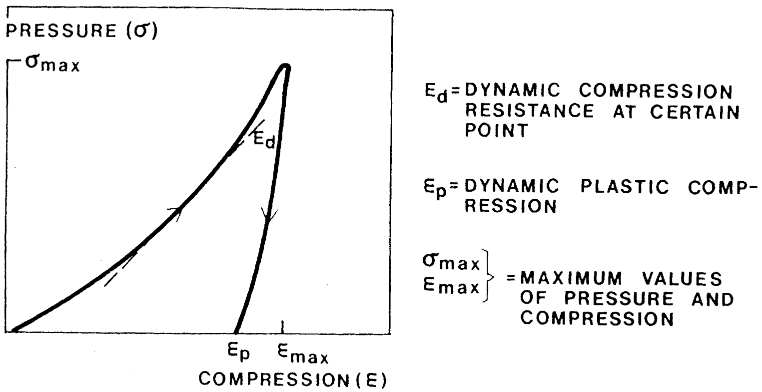

Fig 5—Total pressure in the sample as a function of compression during a dynamic compressibility measurement.

The measurements were carried out by compressing the sample between two metal plates, one with a smooth and the other with a porous surface, the latter replacing the felt. The permeability of the porous surface against water was chosen to correspond to the typical III-press felt in these respects. The special device used for this measurement allowed water permeability of the felt to be measured under compressive load (5).

Of the two quantities to be measured on the sample, one is the compression and the other the total pressure as a function of time during a press-impulse. The compression of the sample was measured at the sample centre by means of an eddy-current transducer inserted in the smooth metal plate. The measurement is calibrated by producing the corresponding press-impulses by means of intermediate plates, the thickness and compressibility of which are known, and by pressing the smooth metal plate directly against the porous one. The total pressure is measured with a strain gauge stress transducer. Both the form and duration of the press impulse can be chosen by means of a computer controlled servo-hydraulic loading apparatus. The design of the press plates is shown in Fig.3.

The press-impulses used consist of a pressure increasing linearly with time (Fig.4) and a descending ramp of constant length. The rise-time of the pressure was varied between 1.5 and 25 msec, while the length of the descending ramp was constant (2.5 msec).

As a result of the measurement we have a graph showing the compression (μm) of the sample as a function of the pressure (MPa) as seen in Fig.5. From this, we can derive the parameters E_d, ε_p, σ_{max} and ε_{max}, which are explained in Fig.5. Furthermore, these parameters can be used to determine some fundamental quantities in wet pressing, including the maximum dry solids content of the sample during pressing, the compression resistance as a function of compression, and the structural pressure generated by the fibre network, this referring to the pressure to be exceeded before dewatering can proceed at all.

Servo-hydraulic load test apparatus

The movement of the smooth press plate can be controlled by means of a servo-hydraulic load test apparatus (MTS-Systems GmbH). The apparatus consists of a load frame, a hydraulic actuator, and a 3-phase hydraulic valve, and 2 pressure accumulators located next to the valve. The control equipment comprises a microcomputer (Digital LS11/23) and a hardware segment generator, which allows the generation of different impulse or wave forms, which can be carried out either in the form of a displacement or press impulse. The shortest impulse that can be generated under maximum load is of about 3 msec duration, with the compression of the material between the press plates at less than 1 mm. The maximum load that can be produced for the test is 50 kN, and the square area of the sample 49 cm^2.

The test equipment comprises a 4-channel transient recorder, the channels of which can be triggered simultaneously by computer, thus enabling the output signals from the various measuring instruments to be received and recorded in synchronized order for further processing by computer.

Samples

The measurements for the purposes of our study were mainly carried out on laboratory sheets, because this was the best way to control the experimental conditions like fibre orientation, which is essential in view of the mechanical properties of the sample sheet. An even humidity was achieved by pressing the samples to the desired initial dry solids content between blotting boards.

RESULTS

Dynamic stress relaxation

The stress relaxation phenomen can be quantified in different ways. For example, the measuring values can be used to calculate the parameter in a chosen mechanical model. One such parameter is the relaxation time constant τ. Alternatively, we can measure the percentage share of stress

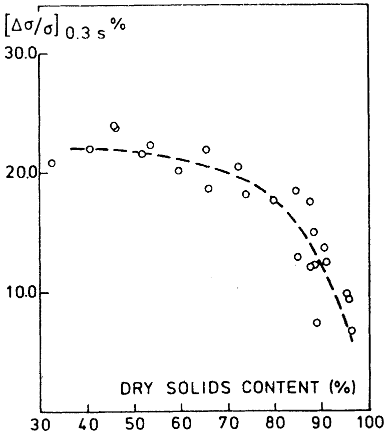

Fig 6—Relative tensile stress (relaxation (△ 6/6). 3 sec (%) (percentage relaxation of stress in 300 m sec) of a newsprint furnish as a function of dry solids content.

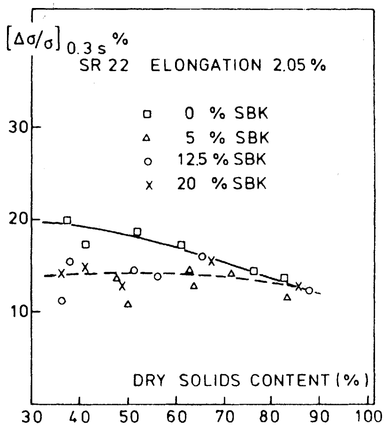

Fig 7—Effect of reinforcing pulp on relative relaxation of newsprint furnish

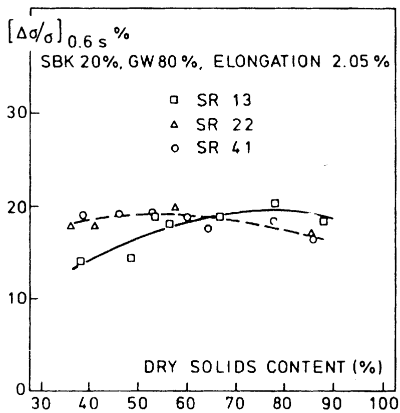

Fig 8—Effect of beating of the reinforcing pulp on relative tensile stress relaxation in a newsprint furnish.

relaxation that takes place within a given time period, and we are not dependent on models. The results presented here represent solely the latter alternative, or proportional relaxation in a specified time, henceforth referred to as the relaxation speed (3).

The effect of the dry solids content

The dependence of the relaxation speed of newsprint on its dry solids content is quite weak as long as the dry solids content is in the range 35 to 75 %. Above the 75 % limit, however, the relaxation speed starts to decline markedly. This can be seen in Fig.6, which presents the relaxation speed of a newsprint sample as a function of the dry solids content. The measurement was in this particular case carried out by increasing the stress on the sample at each measuring point to 70 % of its stress to rupture.

The effect of furnish

The relaxation measurements reviewed below are based on constant strain irrespective of the dry solids content. So the results are not directly comparable with those presented under the preceding item, for which - in order to keep the relative strain unchanged - the strain was reduced as the dry solids content increased.

The effect of the pulp components on the dynamic stress relaxation behaviour was surprisingly weak. Fig.7 shows the effect of the chemical pulp content, semi-bleached pine kraft (SBK) SR 20, on the relaxation speed, when chemical pulp is used as reinforcing pulp. According to the figure, the addition of chemical pulp reduces the relaxation speed especially when the dry solids content is less than 80 %. It should be noted also that this effect is already achieved with very small quantities of chemical pulp.

Fig.8 shows how beating the chemical pulp affects the relaxation speed when the chemical pulp content is 20 %. According to the figure, beating slightly accelerates relaxation with a dry solids content up to 60 %, whereas with a dry solids content exceeding 60 % the effect of beating is the opposite.

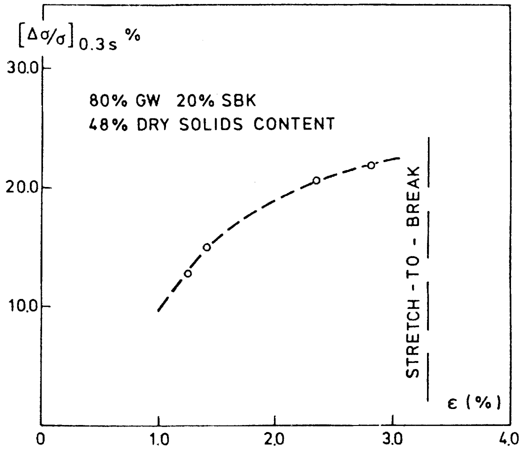

Fig 9—Effect of strain on relative tensile stress relaxation.

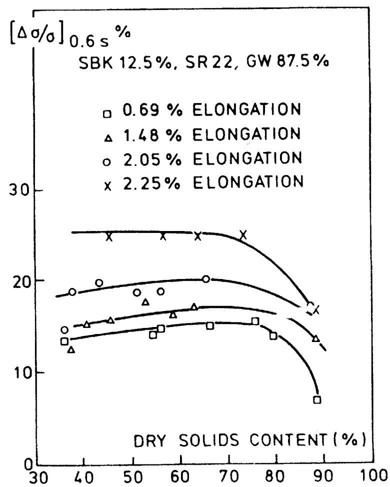

Fig 10—Relative tensile stress relaxation (percentage relaxation of stress in 600 m sec) of a newsprint furnish at different strain levels.

The effect of strain

When measuring relaxation, a certain degree of strain is always produced in the samples. The relaxation speed of the sample increases as this strain is increased. Air dry samples have a characteristic degree of internal stress, below which there is no relaxation and above which the relaxation speed increases steadily immeadiately when strain is introduced (6), whereas at low dry solids contents strain relaxation proceeds at all levels of stress. Fig.9 shows the dependency of the relaxation speed on the strain in a sample with a dry solids content of 48 %. Fig.10 shows the dependancy of the relaxation speed of another sample on the dry solids content with the strain as a parameter.

Dynamic tensile stiffness

The effect of drying stresses on the dynamic tensile stiffness

The effect of drying stresses on the dynamic tensile stiffness is seen in Fig.11. Both laboratory sheets and paper were made of the same pulp, 14 % SBK, 43 % groundwood (GW) and 43 % thermo-mechanical pulp (TMP), in the pilot paper machine at FPPRI. The slips cut from the test machine sheets were rewetted between blotting boards and were then treated in the same way as the laboratory sheets as described under sub-heading "**Samples**" above. To avoid drying stresses, a part of the samples were dried by rolling them lightly between blotting boards to the required dry solids content, whereas the reference samples were dried normally under stress as described above.

At low dry solids contents, the E_d-values of samples dried in the unstressed state seem to be somewhat higher than the respective values of samples dried under stress. This is explained by densification of the sheet during drying between the blotting boards. In laboratory sheets, the effect of drying stresses becomes clearly visible when the dry solids content is above 60 %, after which the increase in the E_d-values of samples dried under stress proceeds at a markedly quicker rate than in the reference samples.

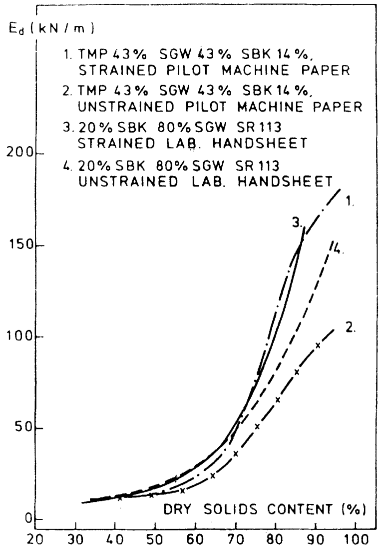

Fig 11—The effect of drying stresses on dynamic tensile stiffness E_d of different furnishes.

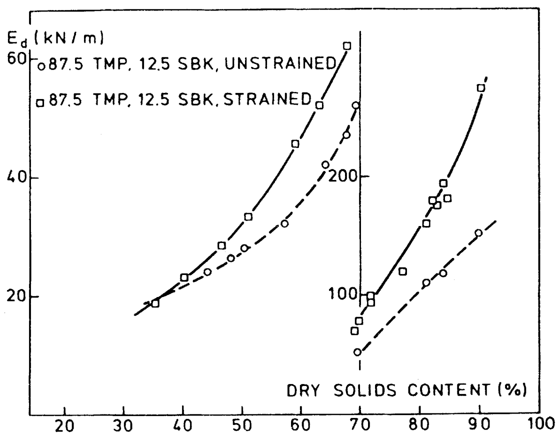

Fig 12—Effect of straining during drying on dynamic tensile stiffness of TMP.

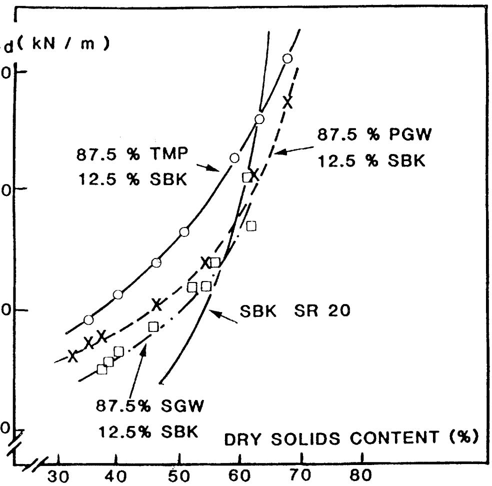

Fig 13—Dynamic tensile stiffness of different mechanical pulps at the same freeness level (CSF 90 ml) and a pure chemical pulp as a function of dry solids ccontent.

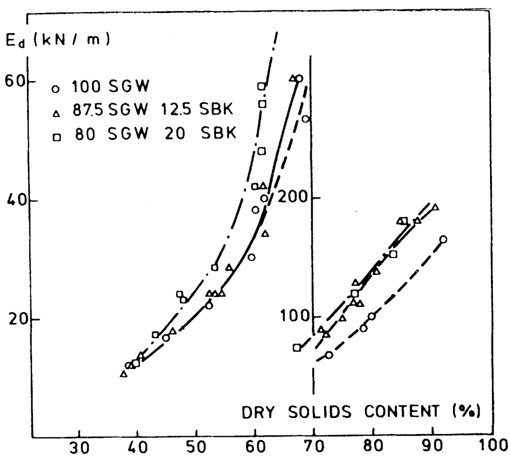

Fig 14—Effect of reinforcing chemical pulp (SBK) on dynamic tensile stiffness of newsprint furnish.

As to the pilot machine samples, the curves representing the samples dried under stress and the reference samples diverge already at a dry solids content below 50 %. At a dry solids content of 90 % there is a considerable difference in the E_d-values.

Fig.14 presents the corresponding curves for laboratory sheets made of TMP and chemical pulp (87.5 % TMP, 12.5 % SBK). The dynamic strain-hardening caused by drying stresses seems to be more intensive in this case than in GW containing furnishes.

The effect of furnish on the dynamic tensile stiffness E_d

The type of mechanical pulp, the proportional amount of reinforcing pulp and the degree of beating affect the mechanical properties of newsprint considerably. In Fig.13, the characteristic in question is illustrated in connection with TMP-, GW- and PGW-mixtures and pure chemical pulp. The comparison between mechanical pulps is carried out at the same freeness level, CSF 90 ml. The differences between pulps are at widest at low dry solids contents (30 to 55 %), i.e. in the range corresponding to the press section and the first part of the dryer section in the paper machine. The dynamic tensile stiffness of TMP at a dry solids content of 30 % is about twice as high as that of GW. The respective value of PGW is about halfway between these two, but it approaches the values of GW, the higher the dry solids content becomes. These proportional differences between pulps diminish significantly as the dry solids content increases.

For the sake of comparison, the figure includes a curve representing the development of the E_d-value of pure chemical pulp as a function of the dry solids content. The curve implies that, at low dry solids contents, the E_d-value of chemical pulp is markedly below the values of mechanical pulps, while at a dry solids content exceeding 60 % the E_d-value of chemical pulp has settled above the curves representing mechanical pulps.

When mechanical pulp is mixed with different amounts of chemical pulp, the result is as seen in Fig.14. According to Fig.14, the curves representing different contents of chemical pulp intersect at the lower end of the scale referring to the

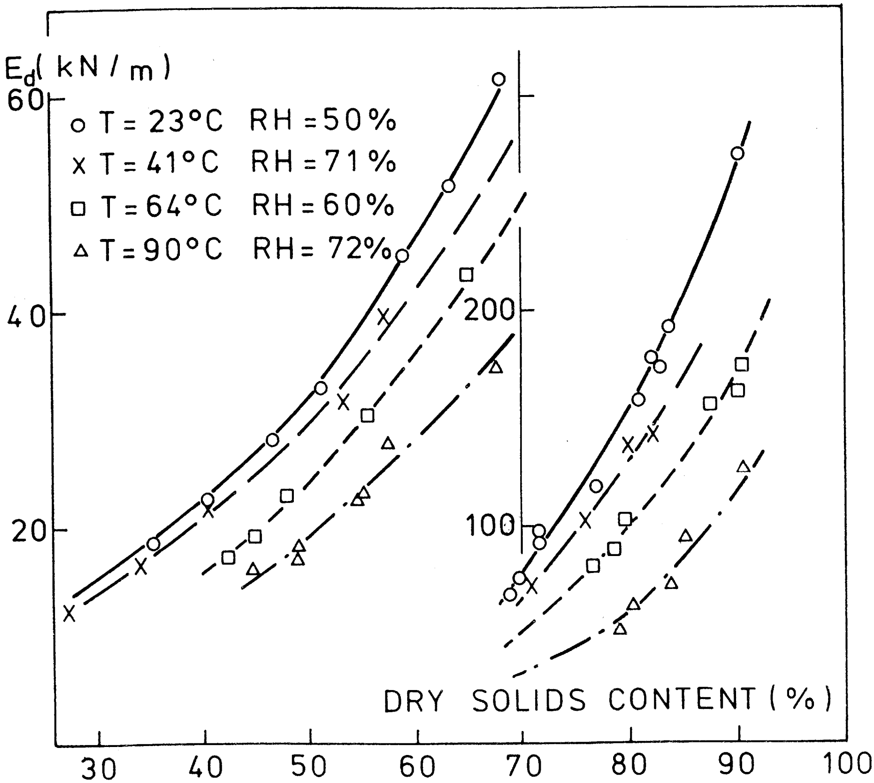

Fig 15—Effect of temperature on the dynamic tensile stiffness of TMP.

dry solids content. The curves representing chemical pulp content between 0 and 12.5 % are almost identical up to 60 %, and their intersection with the curve representing a 20 % chemical pulp content is between 35 and 40 % of the dry solids content.

The effect of web temperature on the dynamic tensile stiffness

The temperature of the web is an interesting variable with respect to its mechanical properties. The effect of web temperature was studied on samples of TMP, PGW or GW mixed with 12.5 % chemical pulp. According to the results, the softening of the pulp components with rising temperature significantly diminishes the dynamic tensile stiffness of the web. Fig.15 presents the E_d as a function of the dry solids content in TMP with temperature as a parameter.

Plastic strain

Fig.16 demonstrates the mode in which plastic strain accumulates during measurement as a function of the dry solids content in three samples. The samples differ from each other as far as the freeness of mechanical pulp is concerned, so they also feature different initial dry solids contents due to similar pretreatment. Plastic strain develops most rapidly at a dry solids content of less than 40 %. At about 40 %, the rate of increase declines sharply regardless of the initial dry solids content. At about a 70 % dry solids content the speed of increase seems to pick up a little, apparently following a sharp increase in the stress amplitude at this level, when the strain amplitude is kept constant to allow for the measuring method.

The dynamic compressibility of the web

The dynamic compressibility was determined and the results analyzed as described under sub-heading "Measurements in the z direction" above. The following results imply the effect of some of the most important variables on web compressibility, from which it is possible to derive mathematical quantities such as the maximum dry solids content, which is calculated using specified fibre and water density values, assuming that the fibre walls themselves are non-compressible. During the

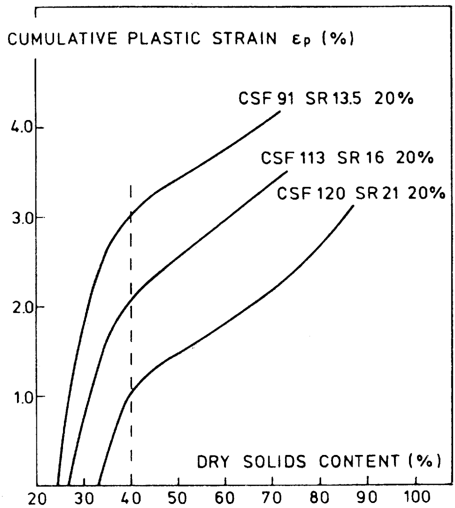

Fig 16—Accumulation of plastic strain of TMP/SBK (furnish at different freeness levels during the test (see also Fig 2).

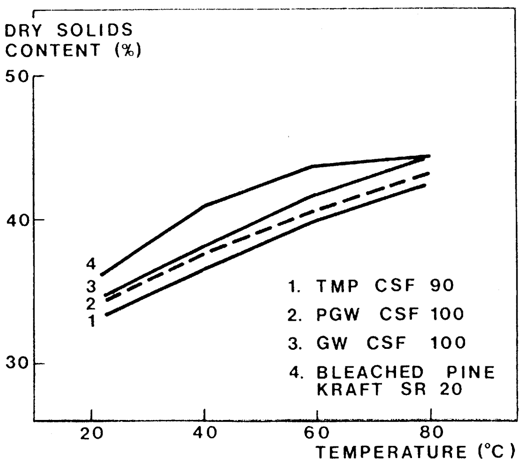

Fig 18—Maximum dry solids content of some pulps during wet pressing as a function of temperature.

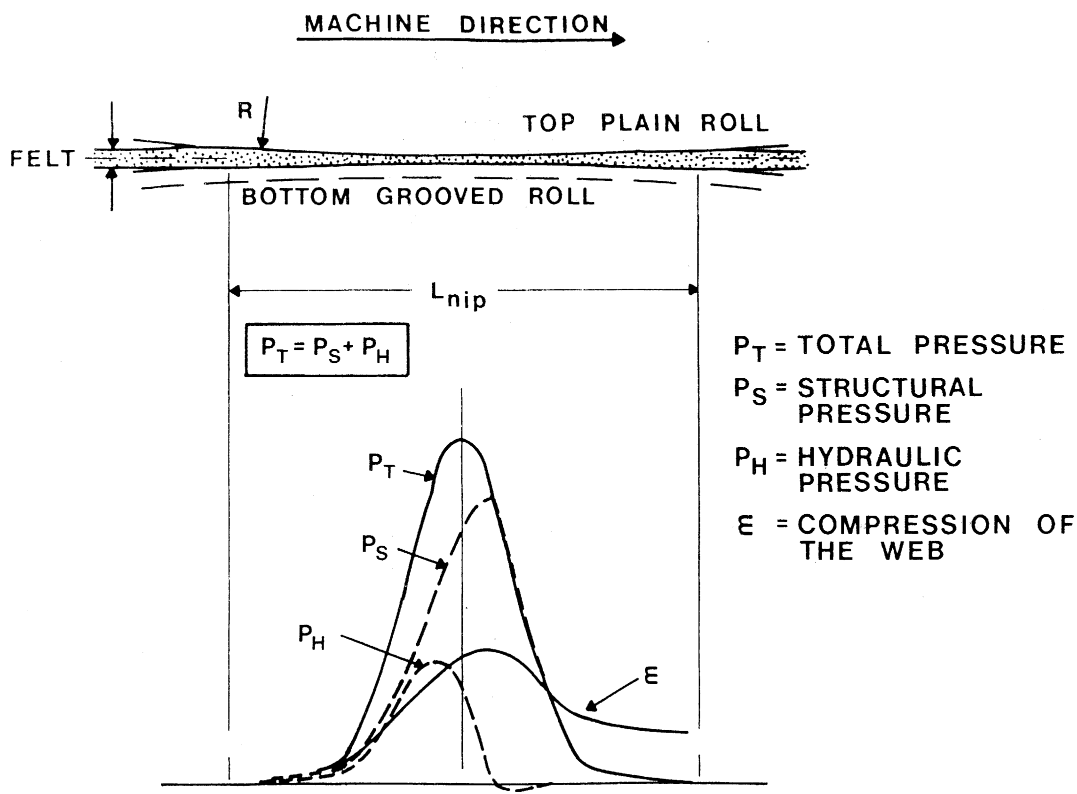

Fig 17—Different pressure components and compression of felt and web in a press nip as a function of time or location in the nip.

test, we measured the sample compressibility as determined on the basis of a specified initial pressure (80 kPa). The sample thickness was determined with a separate gauge, however, under the same pressure.

Fig.17 further outlines the development in time of the different pressure components as well as of the compression of felt and web in dynamic compressibility measurement (7),(8).

The effect of web temperature

These measurements were carried out using the electromagnetic vibrator, described under item "Equipment" above, exceptionally as the loading device and with a small sample area of 2 cm^2.

We used a symmetric sine-shaped press impulse of 2.2 msec duration and at a maximum pressure of 4.5 MPa. The basis weight of the samples was 50 g/m^2. Fig.18 shows the effect of the temperature on the maximum dry solids content derived from the compression of some basic pulps, with an initial dry solids content of 29 %. In the case of mechanical pulps, the increase in the dry solids content progressed relatively evenly following the rise of temperature from 25^oC to 80^oC and was on an average 0.2 percentage points/^oC. In bleached sulphate pulp, the increase in dry solids content was rapid from 25 to 40^oC, but slowed down after that to stop entirely at 60^oC.

Web plasticity in the z direction was also studied as a function of temperature. This was carried out by producing a sequence of 4 compressions at 50 msec intervals using the press impulse specified above and determining the sample thickness 50 msec after the fourth compression. The difference between this thickness and the original sample thickness was then used as a measure of the web's plastic deformation. When analyzing the results, it should be taken into consideration that the sample can between subsequent compressions (50 msec interval) possibly rewet on the porous metal surface. The results of tests with some basic pulps are shown in Fig.19.

Again it was found that the increase in the plastic deformation was rather even in the case of mechanical pulps as the temperature rises from 25 to 80^oC. In the case of bleached pine sulphate, the increase seems to stop already at 40^oC.

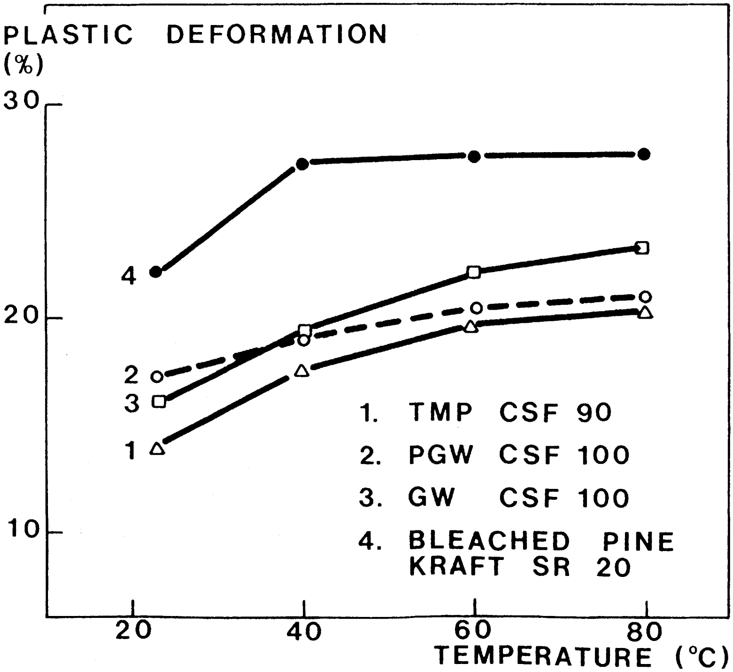

Fig 19—Relative plastic deformation of different pulps in z-direction as a function of temperature based on 2.2 m sec press impulse of 4.5 MPa.

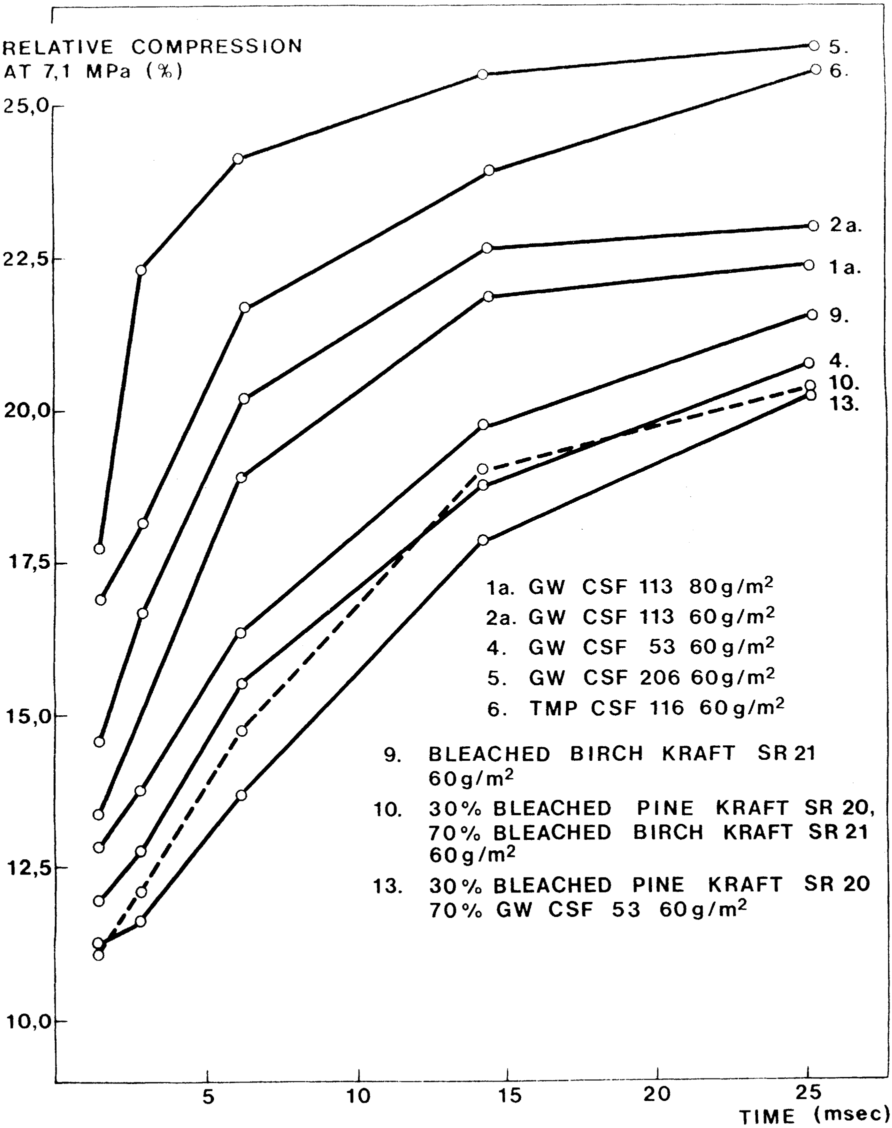

Fig 20—The relative compression of different pulps as a function of press impulse duration.

The effect of the pressing time

The results of our measurements indicate, that the effect of the pressing time on the final results is marked in the range 1.5 to 15 msec.

In Fig.20 we see the relative compressibility of some pulps (compression/thickness of the sample as a function of the rise time of the press impulse, when the press impulse is a rising ramp-pulse as defined under item "Measurements in the z direction" above. It can be seen that in mechanical pulps with a high freeness value, the increase of compression is rapid when the rise-time increases from 1.5 to 5 msec and it tends to slow down already in the 5 to 10 msec range in the case of groundwood (CSF 206 ml). It can further be seen that the relative compressibility of chemical pulp-based pulps and also of low-freeness mechanical pulps is markedly less than of high-freeness mechanical pulps, and so is their speed of compression increase with the rise time of press impulse. The strong effect of freeness on compressibility indicates that the dewatering process of the used samples is partly flow-controlled.

Fig.21 respectively shows the effect of pressing time on the maximum dry solids content of the sample during the press impulse. It justifies almost the same conclusions as Fig.20. In high-freeness pulps the increase in dry solids content is very rapid in the time range 1.5 to 5 msec.

The effect of pre-press dry solids content

To study the effect of dry solids content, the samples were pretreated by pressing them slowly (pressing time 3 min.) between wet blotting boards up to the desired dry solids content.

Fig.22 shows the post-press (output) dry solids content as a function of pre-press (input) dry solids content in some of the pulps studied, when the pressing time was 2.5 msec. When the input dry solids content is in the range 30 to 38 %, the increase in the output dry solids content was on an average 0.8 percentage points for an increase of one percentage point in the input dry solids content. Above this input dry solids

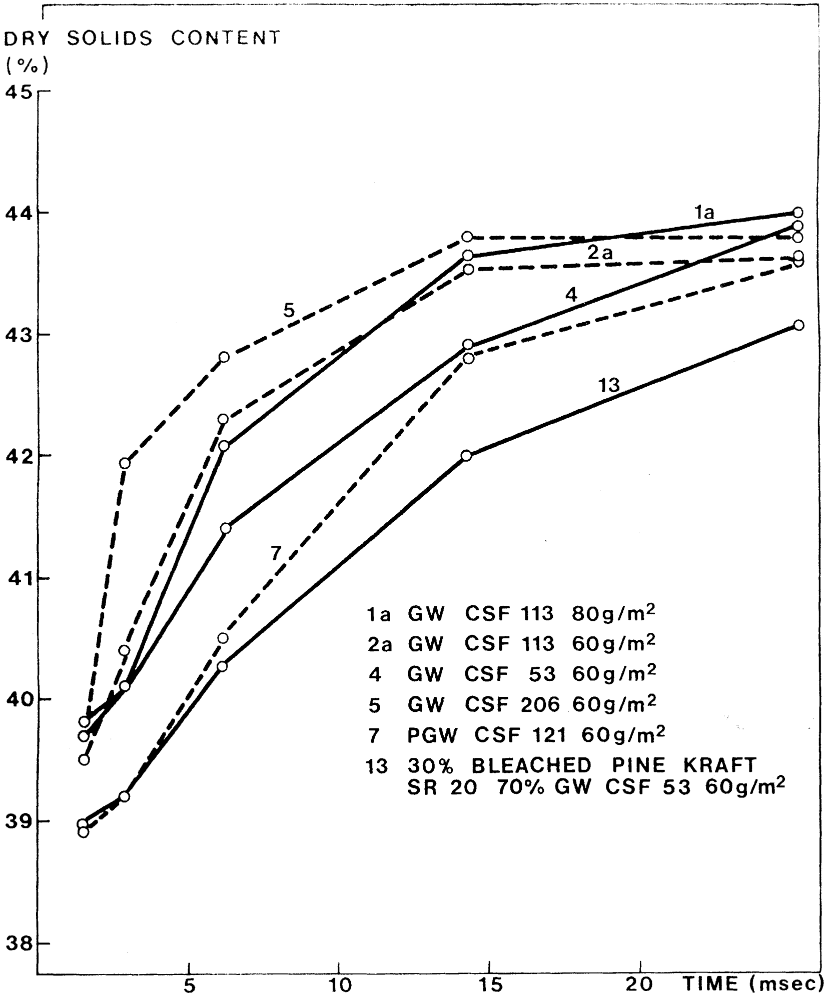

Fig 21—Effect of press impulse duration on the maximum dry solids content of different pulps.

content range (38 to 42 %) the increase in the output dry solids content is slower (0.3 percentage points).

As the wet pressing time is increased to 14 msec, the output dry solids content naturally increases, but the behaviour of its percentage increase as a function of input dry solids content is the same as in the case of a shorter press impulse.

If we look at the compression resistance of the material compressed at the final phase of the press impulse (average between 20 kN and 35 kN), expressed in units MPa/ m, it can be seen in Fig, 23 that this value increases evenly, as the input dry solids content increases from 30 % to 45 %. On the other hand, it can be seen that, when using a press impulse of 2.5 msec, a rise in freeness is apt to diminish this value considerably, and also in chemical pulp-based pulp this value is higher than in the mechanical pulps presented in the figure.

When the pressing time is raised to 14 msec, the effect of the increase in the input dry solids content on the compression resistance becomes less strong. The differences between pulps of various types have also diminished slightly and the compression resistance has declined throughout as can be concluded from the compressibility values presented earlier.

CONCLUSIONS

The outcome of the study (9) can in the first place be used in dealing with problems presented by different loads affecting the web in a paper machine, such as flutter, draws and wet pressing, i.e. the general runability of the machine.

Knowing for example the dynamic modulus and relaxation properties of the web as a function of moisture content and temperature we can in principle estimate the response of the web to mechanical disturbances for example at small areas of high local stress concentration or the whole web in machine direction.

In wet web, the dynamic stiffness is substantially higher than the static modulus. Drying stresses have a strong effect on dynamic stiffness, which essentially contributes to the

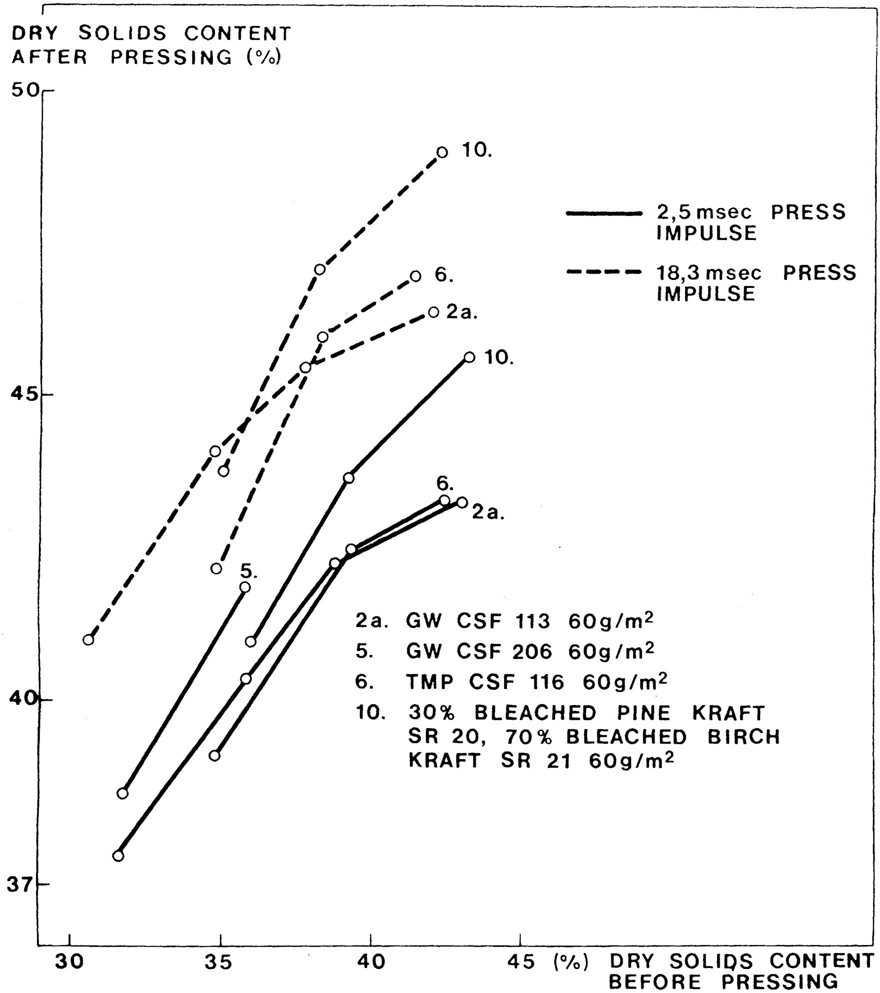

Fig 22—The maximum dry solids content as a function of input dry solids content of some pulps during wet pressing.

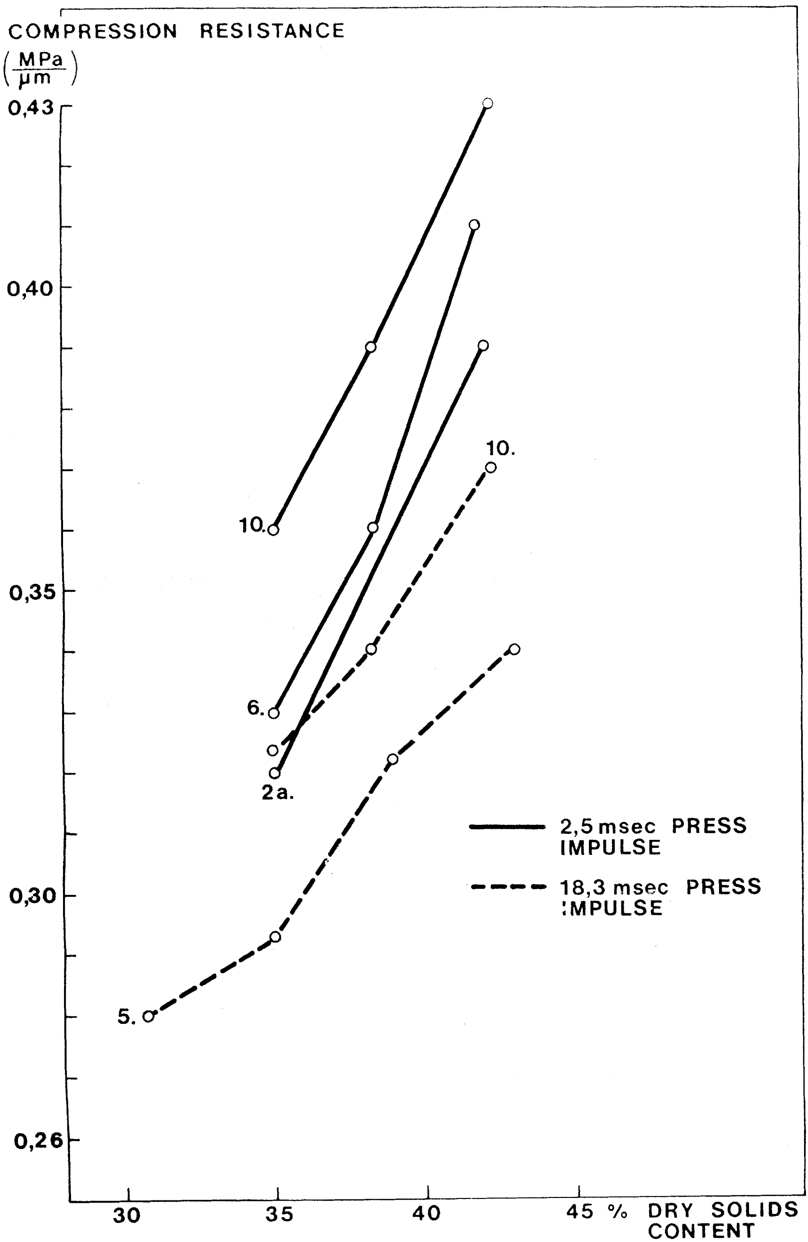

Fig 23—Compression resistance of some pulps as a function of initial dry solids content.

runability, however, only when the dry solids content is in excess of 60 %. When lower, it is possible to influence the dynamic stiffness, for example, through wet pressing and the choice of pulp components.

The results further imply that, especially in mechanical pulps, any increase in the temperature of wet web impairs its dynamic stiffness. The differences between mechanical pulps (TMP, PGW, SGW), are greatest at a dry solids content below 60 %. In this range, the behaviour of chemical pulp is essentially different from that of mechanical pulps. While the dynamic tensile stiffness in mechanical pulps falls rather slowly as the dry solids content decreases, the tensile stiffness of chemical pulp, even when strongly beaten, drops sharply in this range.

The result of wet pressing is primarily dictated by the force and duration of pressing and the temperature of the web to be pressed. In conventional press types, these factors can be enhanced only to a certain, rather low degree. The results of the study contribute to define the influence of these factors on the pressing result within a variation range slightly greater than that in a conventional press.

It is apparent from the results, that a rise in temperature clearly increases the dry solids content and the deformation (loss of bulk) in any type of pulp.

Another significant outcome of the study is the fact that, even in relatively low-weight (50 to 60 g/m^2) paper qualities, the compressibility and with it the dry solids content, substantially increase as the length of press-impulse is increased in the 1.5 to 15 msec range. In mechanical pulps, the build-up speed of compression seems to be most strongly governed by pulp freeness, which implies that the web pressing process is partly flow-controlled also in the case of low-weight printing paper qualities, which supports the idea that extended nip structures should be applied also in these cases.

REFERENCES

1. Jantunen, J., FPPRI internal report 1584, Espoo 1982

2. Johanson, F., Kubat, J., "Measurement of Stress Relaxation in Paper", Svensk Papperstidning 1964 67 (20)

3. Lindberg, J., Johan; Tormala, Pertti "Rheological Models and Processing of Polymeric Materials", Kemia-Kemi 1980, No.5

4. Htun, Myat, "The influence of Drying Strategies on the Mechanical Properties of Paper", Thesis, The Royal Institute of Technology, Stockholm 1980

5. Szikla, Zoltan, Thesis, The Helzinki University of Technology 1985 (unpublished)

6. Johanson, F., Kubat, J., "Internal Stresses, Dimensional Stability and Deformation of Paper", Svensk Papperstidning 1967, 70 (10), 333

7. MacGregor, M.A., "A Description of Sheet Stratification Caused by Wet Pressing", Tappi 1983 66(6), 53

8. Carlsson, G., Linstrom, T., Norman, B., "Some Basic Aspects on Wet Pressing of Paper", Journal of Pulp and Paper Science, September 1983, TR 101

9. Jantunen, J., et al. FPPRI internal reports 1479, 1482, 1498 and 1582, Espoo 1982-1983 and SCAN Forsk reports 377, 380 and 385/1983

Visco-Elastic Properties of Wet Webs under Dynamic Conditions
by J. Jantunen.

Chairman

You have talked about dynamic tensile, dynamic compression, pressing at different temperatures and press impulse. Could you clarify the connection between these properties with respect to the visco-elastic properties of wet webs?

J. Jantunen In case of compression, we have a complex situation with a water, air and fibre network. We are investigating the effect of different raw materials and process factors such as time for example.

Dr. L. Salmén STFI, Stockholm, Sweden

Referring to your dynamic mechanical data, we know that the paper is a highly non-linear visco-elastic material, i.e. the modulus decreases and the loss factor increases with the level of the dynamic strain. How have you accounted for this fact in your measurements?

Jantunen In our case, when we were measuring, we were continually drying the samples so the dynamic stiffness was changing while we were monitoring it. Also, we were increasing the strain because of the creep of the sample, so we tried to keep conditions constant for all samples, then we could look at the differences between different pulps for example.

Dr. J. Mardon Omni Continental, New Westminster, Canada

How do you propose to relate the relaxation characteristics of the wet web to the actual operation of the machine? This is not quite such an easy thing to do.

Jantunen We have not made any calculations to predict the behaviour of various kinds of paper in the paper machine, but if the paper relaxes very fast, the local high strain concentrations have time to relax. Also, in the web open draw after the press section, the relaxation speed affects the tension of the web. For example, if we compare the tension in the wet end and dry end of the paper machine, we will see that in the wet end the tension is a much higher proportion of the stress to break. This is probably because of the higher relaxation speed of the wet web. This is an example of how relaxation affects web tension and runnability in a paper machine.

Mardon That is not quite true. The forces on the web are complete within a millimetre or two of the time that the paper leaves the press roll for example, and the relaxation occurs in the draw afterwards.

Dr. J.R. Parker Bowater Tech. Services, Gravesend, England

In reference to Figure 17 showing the pressure distribution in a nip, of a wet press, are you implying that the total pressure reaches a maximum at the centre point of the nip. I don't think this is the case; it will reach the maximum before the centre of the nip.

Jantunen In the paper machine, it would be the case that the pressure reaches a maximum before the centre of the nip for many reasons. However, Figure 17 was an illustration of a laboratory symmetrical pulse without this effect.

Ibrahim With respect to your reference 8, which is by Dr. Carlsson and Dr. Lindström, showing the distribution of the pressure curves; this behaviour should be identified as to whether it is a flow control regime or a pressure control regime since the two are quite different. In the pressure control regime, the hydraulic pressure is ahead of the mid nip, whereas in the flow control regime, it is after the mid-nip. Also curve E in the figure will behave quite differently. In the flow control regime, it is a straight line.

Chairman

It is correct that our experimental data showed that the hydraulic pressure was slightly ($\approx$ 2 ms) ahead of the mid-nip in flow controlled nips. As these experimental data are in disagreement with any theoretical argument today, we should be careful in assessing the significance of this observation. The time-shift is probably within the experimental error in that specific experiment.