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Prepared contributions

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THE ACTION of a supercalender may be qualitatively explained by applying existing understanding of rolling contact, assuming that the rolls are Hookean. Considering first a nip without paper, the situation is illustrated in Fig. 1*a*. In the contact area, stresses on one body are equal and opposite to those on the other and certain conditions must be met. If the surfaces remain locked over the whole area of contact, it may be shown that the difference of normal strains ($e_{\gamma\gamma}{}^{(1)}$—$e_{\gamma\gamma}{}^{(2)}$) at the surfaces of the rolls must remain constant through the nip. In practice, the shearing stresses must exceed the frictional limit, say, μ times normal stress, near the trailing edge so the contact area is partly locked and partly micro-slipping. It is easier to discuss this situation as follows.

The normal load P gives rise to compressive stresses and strains vertically and horizontally. If the rolls are of the same material, the strains are equal. The shearing stresses from the driving force Q cause normal surface stresses and strains that are equal in size, but in opposite directions (Fig. 1*b*). Long-established theory enables the situation to be drawn as shown in Fig. 1*c*. Micro-slip occurs at the trailing edge, its extent depending *inter alia* on the size of the driving force. If the rolls are of different elastic materials, the compressive strains resulting from all surface stresses are different in each roll. In order to maintain the condition of constant strain difference, additional frictional shear stresses must exist. They have been shown to be of the form shown in Fig. 2*a*, when it is assumed that no micro-slip occurs and no driving force is transmitted.

Although we are extending existing analyses, assumptions associated with the increasingly complex mathematics appear to detract from quantitative deductions. Qualitatively, the total deformations occurring in supercalendering seem to be as in Fig. 2*b* and 2*c*. Confusion is minimised if the established expressions 'creep' be used to express the relative difference in surface velocities, for example, $(1-r_1\omega_1/r_2\omega_2)$, caused by deformations resulting from P and Q and rolling and 'micro-slip' for the unavoidable relative movement of contacting surfaces at the trailing edge.

Note that micro-slip can be expected to occur at both paper surfaces and that most creep at one nip is cancelled at the next when the position of driving and driven rolls is reversed. It is not really cumulative up a calender stack.

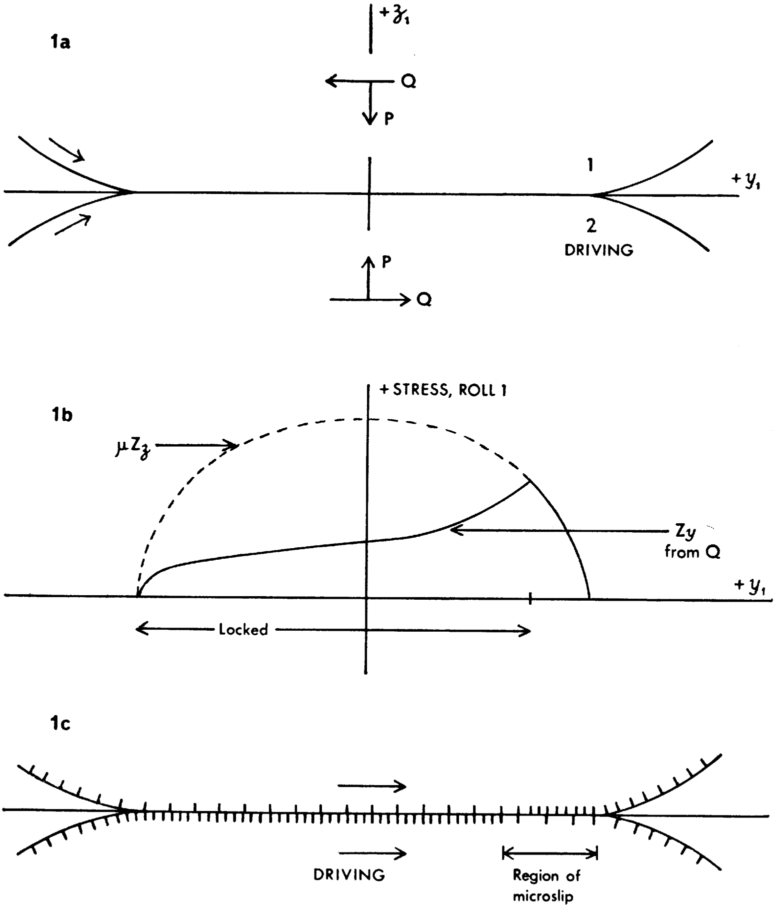
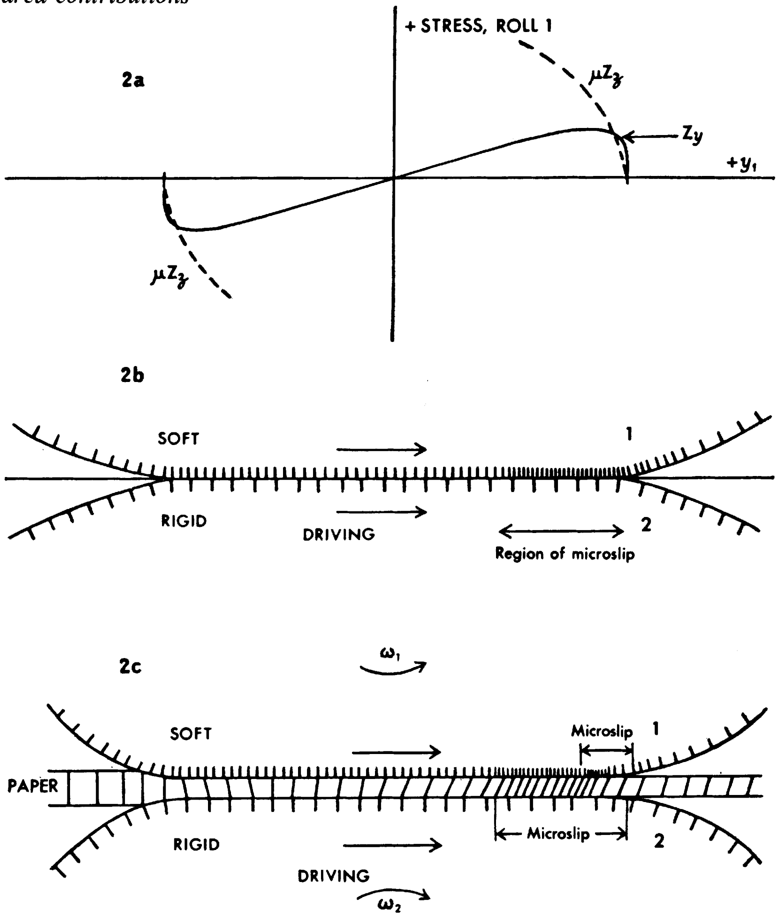


Fig. 1—Stresses and deformations in two elastic cylinders, made of the same material, in rolling contact

Our experiments indicate that 'creep' is about 0.05 per cent. Calculations show that the area of micro-slip is unlikely to occur over more than 20 per cent of the contact area and that contributions owing to the difference in elastic constants and by the driving forces are of similar importance. Sliding is, we believe, an essential feature of the process, but the efficacy of a nip to apply shearing forces as a result of differences in elastic properties should, in theory, depend on the filled roll possessing low Poisson's ratios. We are endeavouring to show that this is so and our results will be published in due course.



F g. 2—Stresses and deformations in a supercalender nip

References

1. Johnson, K. L. in *Rolling Contact Phenomena* (Proc. Symp. General Motors Research Laboratories, Ed. Bidwell, Elsevier Publishing Co., 1960)
2. Bufler, H. *Ingen. Archiv*, 1959, **27**(3), 137–152
3. Mack, H. and Schlegel, P., *Das Papier*, 1962, **16**(7), 277–285

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I WOULD like to give some results from a study of the compressive creep of paper being made at Manchester. This investigation covers ranges of time from 0.006 sec to 6 sec and loads from 1 000 lbf/in^2 to 31 000 lbf/in^2. Both time and load could be varied and controlled independently. Paper furnish and prehistory strongly affect the level of compression, both total and permanent, but a comparison of the effect of applied load and the effect of duration of load application, especially on permanent compression is possible and informative. If the factor by which the duration of the pressure pulse must be increased to give the same permanent compression change as doubling the pressure with no change in pressure pulse duration is called the 'pressure/time equivalence factor', it provides a convenient basis for comparison. Values of 200—10^6 were found for this factor for machine-finished specimens of newsprint, lithographic printing and on-machine coated art papers. Higher values of this factor usually occurred at higher loads.

From Fig. 35, 36 and 37, estimates of the 'pressure/time equivalence factor' can be made by comparing the values of log time at which the lines of constant caliper change across the appropriate values of the pressure. Fig. 35 gives a range of 40–200, Fig. 36 gives 3–8 and Fig. 37 gives 6–16 000 approximately. These values are generally lower than those from the compressive creep study, indicating a comparative insensitivity of the creep tests to the time variable. Since the creep test gave fairly consistent results among three widely differing papers, it is probable that the reason for the difference in sensitivity of the thickness change to 'dwell time' or pulse duration lies in the difference between the two methods of testing.

Claesson & Anderson [1] have shown that it is only at loads over approximately 5 000 atm (45 000 lbf/in^2) that compression of woodpulp is controlled primarily by compression of the fibres themselves rather than by diminution of the void spaces between the fibres. The conclusion on page 611 that results with the dynamic compressibility tester are due to compression of the fibres is at variance with this result. This conclusion is based on similarity of dynamic compressibility characteristics between papers with low and high voids ratios. In the paragraph preceding this conclusion, a similarity to the compression of rubber squares is also noted. It seems probable, then, that the similarity of characteristics is primarily a function of the instrument rather than an indication of the mechanism of compression of the paper.

Some local compression of the fibres must indeed occur because they are not incompressible, but the volumetric compressibility of cellulose is very low compared with the 'compressibility' of a sheet of paper, even with so dense a paper as glassine. Sheet structure must control the diminution of interstices by which most of the apparent volume change of the sheet takes place, so sheet structure and not fibre compressibility must be controlling in sheet compression.

Reference

1. Claesson, S. and Andersson, G., 'P-V Diagrams for some Pulps in the Pressure Range 200–15 000 atm.': *Svensk Papperstidn.*, 1963, **66** (18), 721

Transcription of Discussion

Discussion

Dr J. A. Van den Akker—It is very important, in our opinion, that laboratory devices intended to simulate the action of calenders or any other rolling devices should incorporate the element of shear. In unpublished work a number of years ago, Nolan and I attempted a laboratory study of the effect on the optical properties of paper of mechanical compaction of the damp web. In our initial effort, we set up a precise device for the mechanical compression of the web between plane-parallel steel bosses. On measuring the change in the Kubelka-Munk scattering coefficient for wide ranges in both compaction stress and moisture content (arrived at by desorption from a never-dried web), it was found that the largest changes were very much smaller than that found in the production machine operation, which involved a rolling action on the damp web. In seeking an explanation for this great disparity, I found an important experimental paper by the late Prof. Bridgman (Harvard University) 'Effects of high shearing stress combined with high hydrostatic pressure' (on various organic and inorganic materials).*

This important paper, which showed that the combination of intensive shear and compressive stresses can induce both mechanical and chemical changes at the molecular level, suggested to us that shear should be involved in our laboratory work and, on introducing this factor, we found that we could get on with our work satisfactorily. Although our study was not concerned with calendering, the role of shear in calendering suggested itself and this was later made the subject of an invited article.†

Mr M. I. MacLaurin—Mardon's measurements have been based essentially upon standard stress/time relationship. In a printing press or a calender stack, the more clearly defined relationship is that between strain and time. For example, in a flatbed letterpress machine, the compressive strain of the paper is related to a cosine^2 function of time. This is the sort of relationship he refers to in the fourth quadrant of his nip pressure distribution diagrams.

Some years ago, work in this field was done at Butler's Court, but not

* Bridgman, P. W., *Phys. Rev.*, 1935, **48** (10), 825-847
† *Paper Ind.*, 1946, **28** (1), 57–59

completed owing to changing priorities. The apparatus that was being developed recorded the stress/time for any standard strain/time relationship. Fig. F illustrates the principle.

We used an L.V.D.T. strain pick-up, but Mardon's system appears to be an improvement on this. Do you think the use of this apparatus or other equipment based upon the strain/time reference would give rise to different conclusions from those stated in your paper?

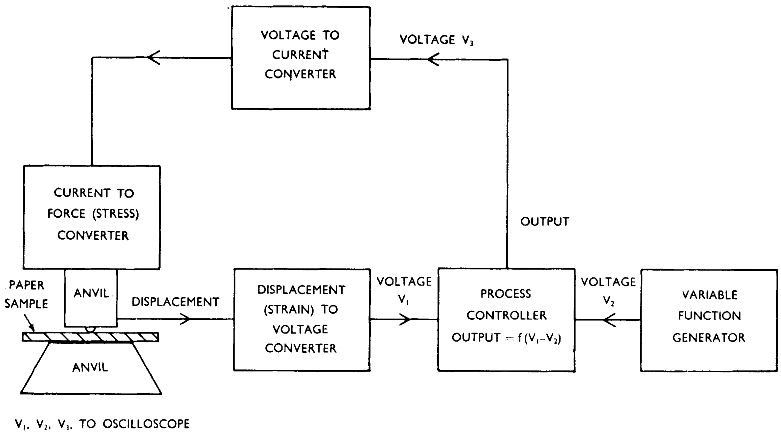

Fig. F

Mr C. B. Ihrman—As a comment to Peel's contribution, I should like to mention a test run on the double-roll compactor with a set speed difference of about 6 per cent. We started with a rather low pressure and the paper had a moisture content of about 43 per cent. The paper came out of the nip neatly cut in strips across the web, which indicated a slip on the entering part of the nip. When the pressure was increased, the same paper was shrunk the normal way. It must be borne in mind, however, that on this run the web covered the steel roll on the in-going side of the nip at least 180°. The trials show that the locked region can be moved in the nip, so that the accelerating rubber on the in-going side of the nip will be found outside of the nip, where it will not destroy the running web.

Mr J. R. Parker—I should like to comment on the relationship between compressibility and printability. Firstly, I believe it is important to distinguish between the compressibility of the body of the sheet of paper and the compressibility of the paper surface, because only a very small proportion of the paper surface can be brought into contact with the printing press—only 10–

20 per cent in the case of newsprint. The stress distribution in the paper surface may be quite different therefore from that within the paper and there may not be a high degree of correlation between the compression of the surface and the compressibility of the body of the paper.

Secondly, the smoothness referred to in the paper has been measured both by the Bekk and Sheffield instruments. Each of these exerts a pressure on the paper that is small compared with the pressure in the nip of a printing press. The pressure in the Sheffield instrument is only 1.46 kgf/cm^2 compared with a possible pressure of 10–40 kgf/cm^2 in the nip of the press. If print rating is to be predicted from the results given by such instruments, therefore, correction must be made for the varying compression of different paper surfaces. I have found that, when smoothness is measured under printing pressures by a suitably designed instrument, no such correction appears to be necessary. I suggest that the compressibility of letterpress papers is not really a fundamental printing property: it is merely a factor introduced to correct for the deficiencies of some smoothness testers.

One final point is in connection with Mardon's Fig. 19 and 20 (page 596). The authors comment that the effect of smoothness on print quality is critical for smooth papers. The shape of these curves, however, is largely a consequence of the method of measuring smoothness. The rate of laminar flow of air between parallel planes is proportional to the cube of the distance between the planes, so the air flow in a smoothness instrument should vary as the cube of mean depth of the surface defects. We have not been given full details of the method of assessing print rating, but if we assume it to be inversely proportional to the depth of the surface pits, the curves shown ought to be of the form—$y = x^3$ and $y = x^{-3}$. This largely explains the results that have been obtained.

Mr J. Mardon—Taking Peel's contribution first, our paper was dealing only with machine calenders, because of the additional difficulties that occur in supercalenders: the only mention of supercalenders was in considering the rather interesting case of glassine. I should point out we were fully aware of the details of rolling friction, with particular reference to Dritowski's work. As a result of discussions with Sir Geoffrey Taylor, the equivalent of Peel's picture is in words in the paper (about four paragraphs on supercalenders). In Peel's particular case, the paper does not come out straight as shown in the diagram, but will run up the slower roll as indicated again in the paper. Although, basically, I agree with him, we may possibly be getting into that region where angels fear to tread.

My only comment on the first part of Chapman's contribution is the fact that there is a variation of one order of magnitude more in his results than ours of the variation in the time/pressure duration relationships. I would not attempt to decide on that basis which results were perhaps more appropriate; it should be possible for him to make an energy balance in the way he did, which would give a very good indication of the accuracy of his instrument. We have given the accuracy of ours.

On the comment (to which I take a little exception) about the similarity of characteristics of the curves for different papers, there is a statement in the paper (page 611) that the voids give a spongy character to the paper, which gives more recovery and so we are aware that the voids play a very great part. As the earlier photographs showed, there is no question that the fibres compressed.

I would like to mention that the specific pressure in the calender stack varies according to the size of the stack approximately 1 000–2 500 lbf/in^2. The bigger stacks do not give the expected increase in specific pressure, because one is widening the nip; so the specific pressure does not increase at the rate at which the total line pressure is going up. It is important to appreciate that the pressure on the fibres is very much greater than the pressure in the nip.

I have no comment on what Van den Akker said, except that our reasons for believing that the flat plate tester gives useful results appear in the text.

I think our results were sufficient for us to be reasonably certain that these very hard, smooth papers were in fact so incompressible after being in the supercalender stack that the differences in compressibility (although quite large compared with the total compressibility) were in fact so small that the compressibility plays a very small part in these particular papers. What plays a more important part in the printability of these papers is the actual surface structure of the base sheet that protrudes through the coating; the screening of the fibres is the vital thing, provided the coating weight is sufficient.

MacLaurin's apparatus looks ingenious, but the only way one can really answer his question is to do the experiment.

Ihrman's comment concerned the passing of the paper through the nip and I agree with him.

Chapman long ago showed that what is important in printability is the printing smoothness, but these incompressible, heavily coated papers are so smooth anyway that they become no smoother when compressed. We are still aware, however, of the importance of printing smoothness. There is a relationship between the compressibility and the printability of a compressible paper like newsprint and I point out again what is stated on page 603 that the force has to be transmitted through the surface to the body of the paper, then through the body of the paper to the packing underneath. Basically, I agree with Parker and thought we had said so.