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EFFECTS OF DRY PRESSING ON PRINTING PROPERTIES OF UNCOATED PAPER WEBS

J. R. PARKER, Engineering and Scientific Services Division, Bowaters UK Pulp & Paper Mills Ltd., Northfleet, Kent

Synopsis—Uncoated paper webs containing groundwood were pressed between surfaces of various hardnesses, using different combinations of pressure and moisture content. The physical and printing properties of the pressed webs were measured. For a given web, the properties that affect print-through such as opacity, scattering power and bulk were determined by the combination of moisture content and pressure that was used. In addition, roughness was influenced by the hardness of the surface used to press the paper. Some treatments gave results similar to supercalendered paper in all respects but for gloss, even though no shear was used during pressing. It was concluded that an optimum degree of compacting existed for paper intended to be printed on both sides.

Introduction

INVESTIGATIONS of calendering and supercalendering have been principally concerned with the progressive change of particular properties of a paper web as it passes through a stack.[1,2] The possibility of slip between rolls both on a macro- and micro-scale has been studied and an experiment on the combined influence of shear and normal pressure has been reported.[3] The existence of micro-slip in the nips of supercalenders now seems to have been confirmed,[4] but no evidence has been found to support the suggestion that roll-to-roll slip occurs in machine calenders.[2] The deformation of the filled rolls of a supercalender plays an essential part in causing micro-slip. In so far as gloss is concerned, this slip may be responsible for the difference between supercalendered and calendered paper, but the direct influence of the filled rolls on the printing properties of paper, because of their ability to distribute nip pressures uniformly despite variations in paper thickness, could also be important.

The possibility of modifying the interrelationship of such properties as bulk and smoothness by the use of different combinations of roll hardness, pressure, moisture content, temperature and slip is of great interest, particularly in the case of such grades of paper as newsprint and mechanical printings, for which there is only limited scope for modifying the furnish. The existence of an optimum degree and type of calendering for uncoated papers, with a view to a particular application, also requires investigation. If letterpress newsprint were calendered too heavily, for example, the improvement of quality by reduction of roughness might be offset by increased print-through.

The evaluation of paper quality by printing tests has never been fully standardised and current interest in the correlations between printing properties and physical tests suggests a need for improved methods of testing paper. Unpublished work on newsprint by the author has revealed that scattering power has a considerable influence upon the darkening by ink penetration of the backs of printed areas and attention was therefore given to this property in the current investigation. A new device for measuring roughness under printing conditions[5] was used to facilitate analysis of the results. This instrument worked on the air leak principle, but its metering land was only 0.005 cm wide—one third of the width of the land used in the Bendtsen instrument. More important was the use of a resilient backing to take up, millimetre to millimetre, thickness variations in the paper and to distribute more uniformly the 20 kgf/cm^2 pressure applied to the paper while measurements were being made. Guard rings were used in the sensing head to minimise permeability errors. Preliminary comparisons showed that the results given by this guard ring instrument were in good agreement with printing tests; the results given below also confirm this view. The readings of air leak instruments were converted from a flow rate to the 'cube root mean cube' gap between the metering land and the surface of the paper.[5] This conversion is based on the assumption that the air flow could be calculated by treating this non-uniform gap as a series of parallel-walled channels.

Experimental design

SAMPLES for printing were prepared by pressing paper webs between flat plates at room temperature in a hydraulic press. This method was selected, because it could be accurately controlled: it enabled the effects of the surface hardnesses of the plates to be studied at known pressure levels. It was assumed that, even though the pressure would be applied to the paper for a much longer period and the temperature used would be lower than in a stack, the important variables would interact in the same way as in a mill calender or supercalender.

Pressing treatments were selected according to a one-third fractional factorial design for four factors—type of web, packing softness, preconditioning humidity and pressure—each at three levels. The design adopted is discussed by Davies:[6] it enables main effects and certain two factor interactions to be studied without confusion, but a formal analysis of the results has not been attempted. The chief merit of the design was that it provided 27 different treatment combinations, consequently a wide range of paper properties that would highlight any interesting fields for further investigation and would also permit the interrelationships between physical and printing properties to be studied. Details of the treatment combinations selected are given in Table 3. The letter and figure before each observation refer to the paper web and softness of packing used.

Preparation and testing of samples

THREE paper webs were selected to cover a range of substance, furnish and clay content (Table 1). Each web was cut into sheets, which were randomised before the experiment. The three moisture levels were provided by oven-drying samples of the webs for 20 min or conditioning them for at least 2 h at 50 or 80 per cent relative humidity. Minor changes in moisture content occurred in the subsequent manipulation of the webs, because the hydraulic press was not in a conditioned atmosphere. Average moisture contents during pressing are given in Table 2.

The samples were pressed between 3.8 cm × 16 cm flat steel plates. To simulate the fibre rolls of supercalenders, sheets of compressed paper were introduced during pressing first on the wire side, then on the top side of the web. Each sample was therefore pressed twice, even if no packing was used and was turned end to end between pressings. The compressed paper sheets used as

TABLE 1—PAPER PROPERTIES OF WEBS BEFORE PRESSING

Paper symbol	*Description of paper web*	*Substance, g/m²*	*Bulk, cm³/g*	*Groundwood, per cent*	*Luminance (R_∞)*		*Ash, per cent*	*Side selected for printing tests*
					Top side	*Wire side*		
D	Telephone directory, sampled after machine calender, before supercalender	42.3	1.90	60	0.700	0.696	6.6	Top side and wire side
N	Newsprint, sampled after machine calender, before supercalender	54.6	1.94	83	0.667	0.678	2.2	Wire side
M	Magazine, sampled before machine calender	64.0	2.21	72	0.717	0.708	14.4	Top side

TABLE 2—DRY PRESSING VARIABLES

Level of variable	*Type of packing*	*Pressure, kgf/cm²*	*Preconditioning humidity, per cent*	*Average moisture content of paper during pressing, per cent*
1	None	230	Oven-dry	0.6
2	Two sheets of parchmentised G.I.P., 42 g/m²	520	50	7.7
3	Eight sheets of compressed standard sheetmachine blotter	1 220	80	12.4

packings were permanently plied together and were rotated systematically so that their outer layers came into contact alternately with the web and with the steel plates. Roughness induced in these packings by the paper would therefore be corrected to some extent by contact with the smooth metal surface. The packings were dried or conditioned with the paper to prevent moisture transfer in the press between paper and packing. At each pressing, the pressure was increased at a rate of 100 kgf/cm^2/sec to the desired level and was then held constant for 10 sec. After pressing, all samples were conditioned for 16 h at 50 per cent rh and 20°C before they were tested.

The physical tests were performed upon the actual areas to be printed. No evidence of damage by testing could be seen in the prints, so it was assumed that this method was satisfactory. Details of the methods used are given in the appendix.

A Vandercook universal proofing press was used to make solid prints on the pressed areas. The press blanket consisted of a 0.020 in rubber sheet, under which was a 0.005 in polyester film bonded to a 0.015 in rubberised cork sheet. The press speed was 100 ft/min and the nip load was 13.4 kgf/cm. It was estimated that this load corresponded to a peak pressure in the nip of 20 kgf/cm^2. Four prints were made on each sample, on the sides indicated in Table 1. For each set of prints, the thickness of ink on the printing plate was adjusted to cover the range 0.8–2.0 of the absolute roughness of the sample as indicated by the guard ring instrument. A 14 poise news ink was used and the polished aluminium printing plate was weighed before and after each print. Print reflectance and print-through were measured after 24 h.

Print quality was assessed by comparing the prints with the solid panels in a variety of half-tone prints that had previously been ranked with particular attention to the tone range and detail that could be discerned. The prints were all backed with unprinted paper during this comparison. Allowance was made for the differing reflectances of the unpressed paper webs, but not for the moderate darkening of the paper that was caused by pressing. Quality numbers (Q) had been assigned to the half-tone prints during their initial ranking and corresponding Q numbers were given to the solid prints. These ranged from zero to 6.7; unit difference indicated an obvious difference in print density or uniformity. For uniform prints, the density difference per unit of Q was 0.125 and a quality of 5 corresponded to a blackness contrast of 0.85.

Optical properties and bulk of pressed paper

APART from sheet substance, the only important property that was unchanged within the limits of experimental error by pressing was light absorption power. This suggested that no chemical degradation of the fibres was caused by the pressing treatments. Scattering power was decreased by pressing. This effect was particularly marked when both pressure and moisture content were high: of the three webs, the decrease was greatest for M. It appeared to be related to clay content. The softness of the packing had no influence on scattering power, except that, when the highest pressure and moisture level were used in combination, the soft packing seemed to cause the scattering power of paper M to fall disproportionately. This may have been due to error in measurement of bulk caused by the roughness of this sample.

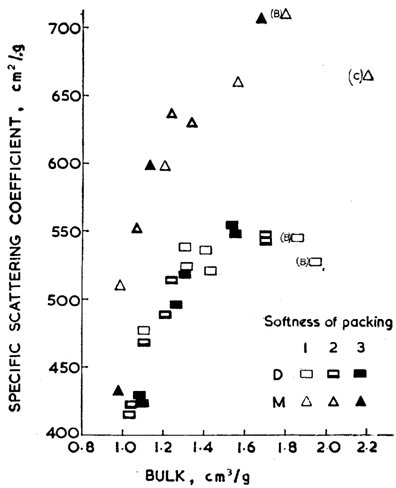
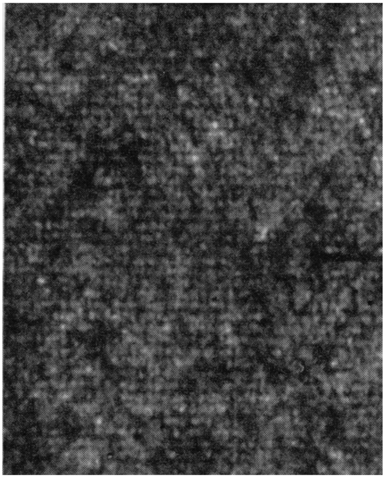
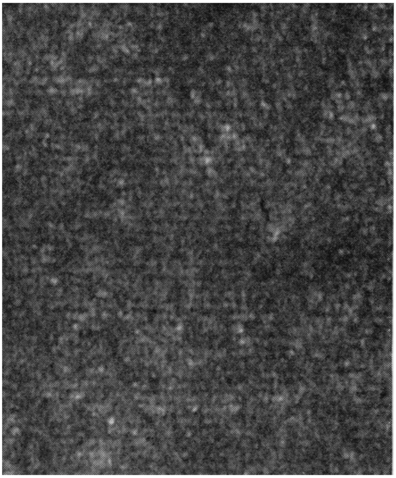


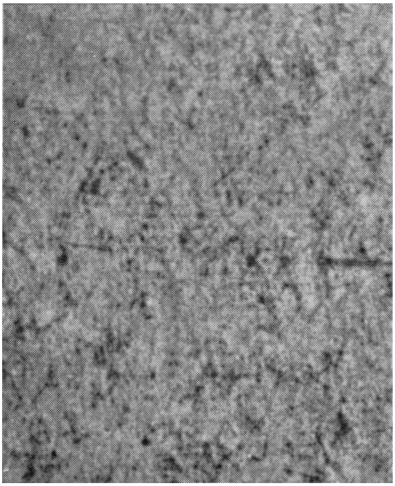
Fig. 1—Relationship between specific scattering coefficient and bulk—
B: sampled after machine calender
C: sampled before machine calender
(web N omitted for clarity)



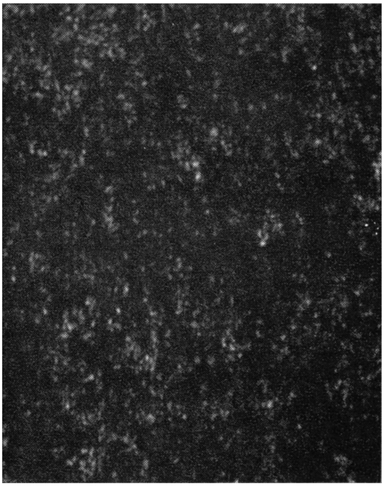
(*a*) Before pressing: wire side viewed by transmitted light



(*b*) After pressing: same area seen by transmitted light

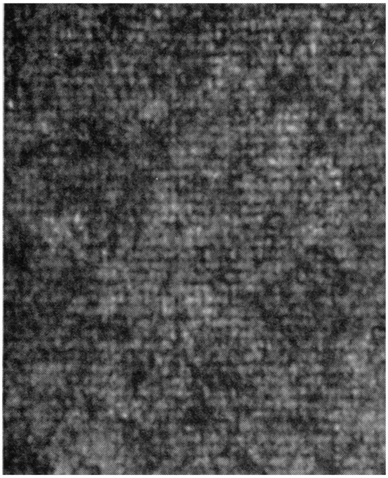


(*c*) Print-through: mirror image of top side, showing black flecks caused by translucency of high substance areas, viewed by reflected light

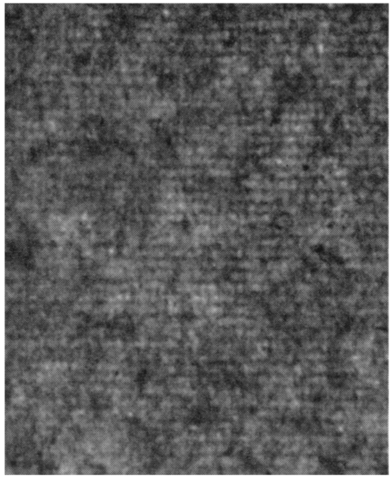


(*d*) Printed wire side of paper seen by reflected light: 1.29 g/m^2 ink on the paper

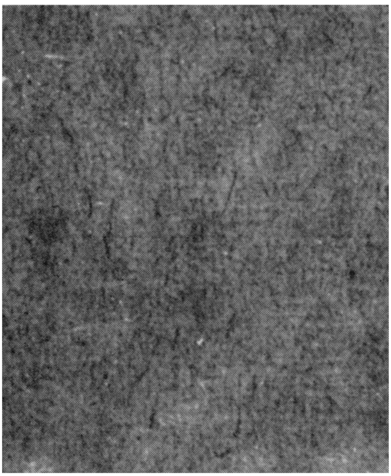
Fig. 2—Web D pressed twice between steel plates at 1 220 kgf/cm^2 pressure: approximate web moisture content 7.7 per cent [× 3]



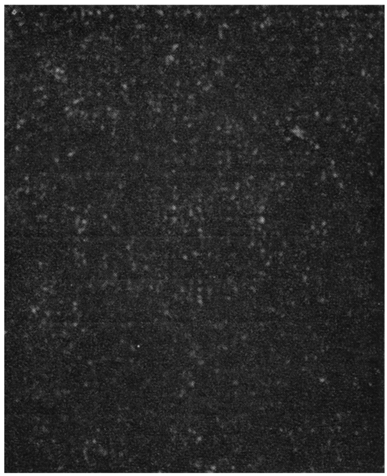
(*a*) Before pressing: wire side viewed by transmitted light



(*b*) After pressing: same area seen by transmitted light



(*c*) Print-through: mirror image of top side, showing slight mottle, viewed by reflected light at increased contrast



(*d*) Printed wire side of paper seen by reflected light: 1.27 g/m^2 ink on the paper

Fig. 3—Web D pressed twice with 8 plies of compressed blotter as soft packing at 1 220 kgf/cm^2 pressure: approximate moisture content 7.7 per cent [$\times$ 3]

TABLE 3—DATA FOR THE BULK OF PRESSED WEBS

The letter and number before each observation indicate the type of web and packing softness

Pressure level	*Moisture level*		
	1	2	3
1	D2 = 1.70 N1 = 1.83 M3 = 1.69 *Average* 1.74	D1 = 1.42 N3 = 1.59 M2 = 1.35 *Average* 1.45	D3 = 1.28 N2 = 1.40 M1 = 1.21 *Average* 1.30
2	D3 = 1.54 N2 = 1.69 M1 = 1.57 *Average* 1.60	D2 = 1.22 N1 = 1.39 M3 = 1.13 *Average* 1.25	D1 = 1.11 N3 = 1.22 M2 = 1.07 *Average* 1.13
3	D1 = 1.31 N3 = 1.40 M2 = 1.25 *Average* 1.32	D3 = 1.08 N2 = 1.12 M1 = 0.975 *Average* 1.06	D2 = 1.04 N1 = 1.05 M3 = 0.965 *Average* 1.02

Bulk followed a similar pattern to scattering power and was unaffected by the softness of packing (Tables 3 and 4). Not surprisingly, plots of specific scattering coefficient against bulk (Fig. 1) showed that these two properties were highly correlated, although a separate regression curve was necessary for each web. There was some suggestion, however, that the scattering power curves passed through maxima at bulks between 1.6 and 1.8. This effect was

TABLE 4—MAIN EFFECTS OF PRESSING TREATMENTS ON BULK

Level of factor	*Paper*	*Packing softness*	*Moisture*	*Pressure*
D, 1	1.30	1.32	1.55	1.50
N, 2	1.41	1.32	1.25	1.33
M, 3	1.25	1.32	1.15	1.13

ill-defined and requires confirmation; if it exists, it shows that fibres or fibre bonds are ruptured by pressing. Scatter around the curves corresponded to less than $\pm$ 5 per cent error in specific scattering coefficient and was apparently unrelated to the pressing conditions.

The luminance and opacity of the samples follow from their scattering and absorption coefficients. The darkening of pressed areas is shown by this experiment to be a result of the increased optical contact between the interfaces within the paper, not to the production of coloured material in the web.

Visual comparison of the webs showed that packing softness had a considerable effect on the appearance and look-through of the pressed samples, even though it did not affect their average optical properties. When no packing was used, the improvement of the look-through of the paper pressed to a low bulk was very great (Fig. 2). Cloudiness almost disappeared and shives became transparent. When viewed by diffuse top illumination, such shives seemed to have been darkened by pressing. When soft packing was used (Fig. 3), pressing had much less effect on the appearance of the samples. These differences were subsequently compared with the effects of packing softness upon the uniformity of thickness and bulk.

Guard ring roughness

THE guard ring roughness of the wire sides of the webs was found to be determined by the combinations of moisture content and pressure that were

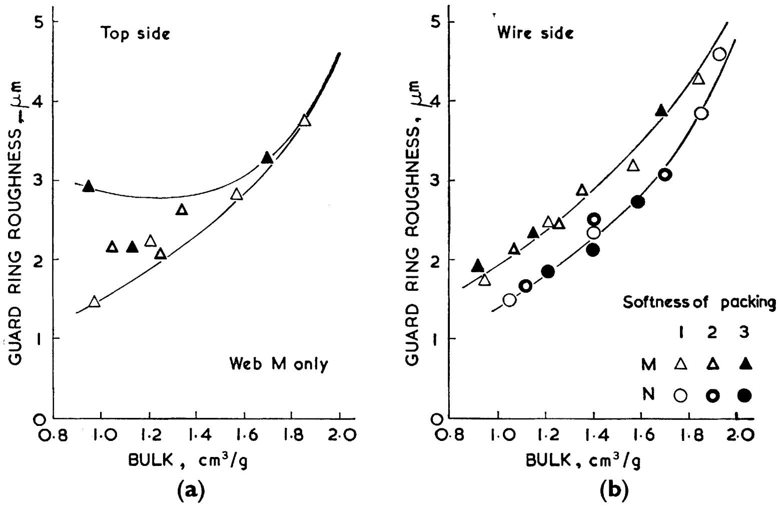


Fig. 4—Printing roughness compared with bulk: the upper and lower lines in (*a*) indicate limits of roughness variation caused by compressing webs with soft and hard packings

used; consequently, roughness was highly correlated with bulk. At a given bulk, the newsprint web was less rough than were the other webs, probably because it contained less chemical woodpulp (Fig. 4*b*). Packing softness was apparently unimportant, but this was later found to be a consequence of the pressing routine. Compared with the results produced by pressing with steel plates only, the first pressing with a soft packing against the wire side left this side of the web appreciably rough and the top side relatively smooth. During the second pressing, with the packing against the top side, the roughness of the wire side was corrected by its contact with the steel plate, but the top side was roughened to an extent that depended upon the pressing conditions.

In Fig. 4*a*, the top side roughness of the magazine web is shown plotted against bulk. At high bulks, for which the packings would have been relatively hard compared with the paper, packing softness has little effect. At low bulks, however, the scatter of the points is appreciable. The roughest samples in this low bulk region resulted from the use of the softest packing at the highest levels of pressure and moisture content. The high moisture level probably increased the softness of the packing, because the packings were conditioned with the paper before pressing. The top sides of all three webs showed the same effect, but it seemed least marked for the newsprint web *N*. There was some indication that, when the high moisture content and soft packing were used in combination, there was a limit to the smoothness that could be attained by increase of pressure. This is indicated tentatively by the upper curve in Fig. 4*a*. When no packing was used, the top sides of the webs behaved similarly to the wire sides and, at a given bulk, the smoothness seemed to be unaffected by the combination of pressure and moisture content used during pressing.

Bendtsen roughness, thickness variation and permeability

BENDTSEN roughness was included in the physical tests and it is of some interest to compare it with guard ring roughness. The most striking difference is in the effect of the softness of the packing. Paper pressed between steel plates was generally much lower in Bendtsen roughness than paper pressed with a soft packing—a difference that was most marked when pressure and moisture content were both at a high level. Even when the roughness was converted to absolute units, the effect of packing was exaggerated; for this reason, the Bendtsen roughness was in very poor agreement with the roughness indicated by printing tests. Some factor other than printing roughness was affecting the instrument and it was suspected that this was the *flatness* of the paper. Bendtsen roughness is measured with the paper backed by a glass plate, so that thickness variations several millimetres in wavelength could allow air to leak beneath the metering land and contribute to the roughness reading. Because of the resilient backing and greater land pressure used in the guard ring instrument, such thickness variations would not prevent the paper surface touching the metering land at frequent intervals and would therefore not affect the readings of the instrument any more than they would affect print quality. Paper pressed between steel plates would be expected to become uniform in thickness, despite substance variations, but a soft packing would distribute pressure more uniformly and reduce the paper to a uniform bulk and non-uniform thickness. Reference to this effect has already been made in connection with the uniformity of opacity and confirmation of the theory was obtained in various ways.

The thickness variations were measured by taking thickness readings in groups of five within 10 mm diameter circles on single sheets. A 1 mm diameter anvil was used with a 100 g load. Standard deviations were calculated from the mean range of thickness within such circles. The results are compared with roughness measurements in Table 5. As a further check, air

TABLE 5—SOME EFFECTS OF THICKNESS VARIATIONS CAUSED BY SOFT PACKINGS

Data measured	*Webs pressed twice between steel plates*		*Webs pressed twice with 8 blotter packing*	
Dry pressing pressure, kgf/cm²	714	1 220	714	1 220
Standard deviation of thickness, μ	2.5	2.7	7.6	10.6
Bendtsen roughness in absolute units at 1 kgf/cm²: mean of top side and wire side, μ	4.5	3.9	7.4	7.7
Guard ring roughness at 20 kgf/cm²: mean of top side and wire side, μ	1.94	1.55	1.91	1.72
Bendtsen permeability, ml/min at 150 mm w.g.	134	88	101	44

permeabilities were compared. Although the substance and the bulk of the sheets were the same, the permeability of the sheet pressed with soft packing was low. This indicated that the effect of packing softness on Bendtsen roughness was not due to a permeability error; it also showed that the bulk of the web pressed with soft packing was, as anticipated, the more uniform, since the permeability varied approximately as the square of the void fraction of the paper webs studied.

Air permeability can be used to estimate very approximately the rate at which ink would penetrate into the surface of paper under the influence of external pressure. For viscous flow, if the effects of pigment and compression of the paper are neglected, it can readily be shown that the ink penetration index (that is, the rate of flow of ink into the paper under unit pressure when unit thickness has already penetrated) is given by—

$$A = qw(B-B_0) \quad . \quad . \quad . \quad . \quad (1)$$

where q is the air permeability, w the substance, B the bulk and B_0 the bulk that the paper would have at zero void fraction. The ink absorption index was calculated without conversion factors using Bendtsen permeability measured at 150 mm w.g. When plotted against bulk it was found that, at a given bulk, the index of papers pressed with soft packing could be as little as one third of the index when no packing was used.

Ink requirement and ink transfer

The roughness of paper can be estimated from printing tests in a variety of ways, using for example, the Lehigh transfer equation,[7] the method

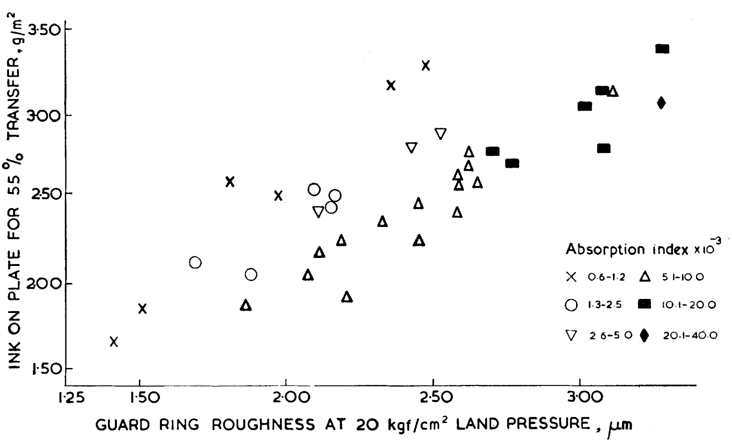


Fig. 5—Ink on printing plate required to give 55 per cent transfer compared with roughness and ink absorption index

developed by Hsu[8] or Ginman's *E* test,[9] which is the amount of ink required on the printing plate to give 50 per cent ink transfer. For the work under discussion, the quantity of ink required to produce a particular result was the most convenient measure of printing roughness for use with the limited numbers of prints available.

The weights of ink necessary on the printing plate and on the paper to produce a print of 12.5 per cent reflectance, print qualities of 3.0 and 5.0 and an ink transfer of 55 per cent were therefore found graphically. It soon became clear that three factors were affecting these ink requirements. The ink on the plate that gave a print reflectance of 12.5 per cent depended only on the guard ring roughness (Fig. 4[5]). The ink on the plate to produce 55 per cent transfer—a quantity very similar to Ginman's *E*—depended both on the roughness and on the ink absorption index calculated as described above (Fig. 5). The amount of ink on the paper necessary to make a print of specified quality was related to the guard ring roughness, but it also decreased with the softness of packing used during pressing (Fig. 6). The other relationships follow from this—for example, the ink on the printing plate necessary to produce a print of given quality would depend on roughness, packing softness and ink absorption index. A statistical analysis might modify those conclusions slightly, but would be unlikely to affect their practical implications.

The effect of packing upon the ink requirement for a given print quality is a result of the increased uniformity of the prints caused by the use of softer packings. Prints made on paper pressed with no packing showed appreciable mottle—that is, density variation at wavelengths of a few millimetres (Fig. 2)

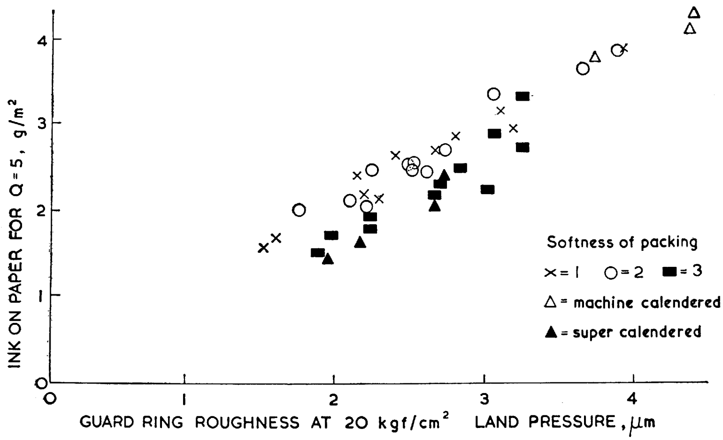


Fig. 6—Quantity of ink on the paper necessary to produce a print of given quality plotted against printing roughness

—and they were consequently penalised. By comparison, the use of soft packing resulted in prints in which the small uninked areas appeared to be uniformly distributed. It will be recalled that the webs pressed with steel plates were uniform in thickness, therefore non-uniform in bulk and also, presumably, in roughness. The mottle caused by the steel plates was the result of this roughness variation. Its correlation with the opacity variations of unpressed paper can be observed by comparing Fig. 2*a* and 2*d*.

There was no indication that any of the correlations between ink requirement and roughness were seriously affected by the combination of pressure and moisture content used to achieve a given roughness. The effects of dry pressing upon the different measures of ink requirement can therefore be deduced from the effects of dry pressing on roughness and ink absorption index (discussed above) and from the softness of the packing.

Print-through

PRINTED opacity is measured by the ratio R_0^{PB}/R_∞ and print-through may be defined as $(1-R_0^{PB}/R_\infty)$, where R_0^{PB} is the luminance of the back of a print with black backing and R_∞ is the luminance of an opaque stack of paper. Sometimes R_∞^{PB} is substituted for R_0^{PB} in the definition of print-through, but the definition used here has certain advantages. For prints made on uncoated papers that contain no oil-absorbent fillers, a graph of R_0^{PB}/R_∞ plotted against the weight of ink per unit area of paper (Fig. 7) gives a straight line of negative slope and an intercept with the abscissa equal to the printing opacity R_0/R_∞. Some scatter is caused by substance variation, but there is no

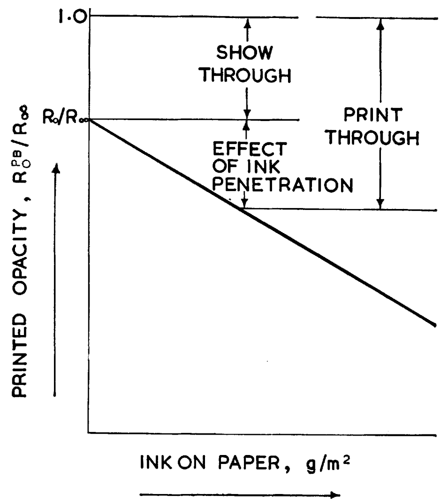


Fig. 7

significant curvature. The slope of the line, multiplied by 100 with the negative sign ignored, will be called the *ink penetration index*. For a given ink, this quantity and the opacity define the relationship between the amount of ink on the paper and print-through. They can therefore be used to calculate print-through at given blackness contrast from the appropriate ink requirement.

A plot of ink penetration index against scattering power for the pressed samples is shown in Fig. 8. For a particular paper, it is evident that scattering power could be used to predict ink penetration coefficient with reasonable accuracy. The scatter of the points is probably due to error: it bears no simple relationship to the pressing conditions. Previous experiments by the author on a wide range of newsprint samples suggested that there was a general relationship between ink penetration index, scattering power and bulk, but fillers may modify this correlation.

In Fig. 9, the printed opacity for a specified print quality is plotted against bulk for each of the pressing treatments. The vertical scatter of the points for each web is partly the result of substance variation and experimental error, although there is also some variation because of the effect of packing softness upon the roughness and ink requirement of the paper. The machine-calendered and supercalendered samples corresponding to *M* were not sampled at quite the same time as the part of the web used for pressing. Since they

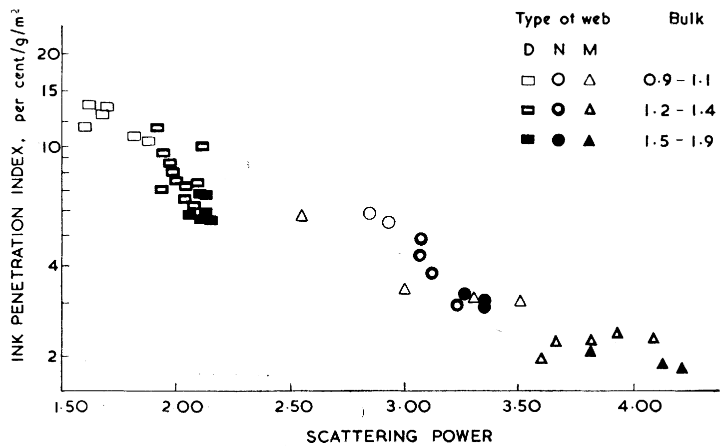


Fig. 8

were relatively high in scattering power, they consequently gave higher printed opacities than the pressed samples. Despite these errors, the prints are distributed about curves that exhibit broad maxima and fall off rapidly at low bulks. This is a result of the changes in the relationship between ink requirement and resistance to print-through brought about by the pressing treatments. At low bulks, the reduction in scattering power and bulk outweighs the advantage of decreased roughness. It is usually desirable to calender paper so that its roughness is as low as possible, without incurring a serious increase in print-through. The results for the supercalendered samples plotted on the graph suggest that this ideal has been achieved.

For the maxima of the curves to correspond precisely to optimum printability, it would be necessary to weight the print quality according to the minimum size of the half-tone screen that could be used. Screen size would probably depend on the amount of ink required on the printing plate to produce a given print quality and, although this could be determined from the data given by the experiment, a method for combining all these factors into a single numerical measure of printability has not yet been devised.

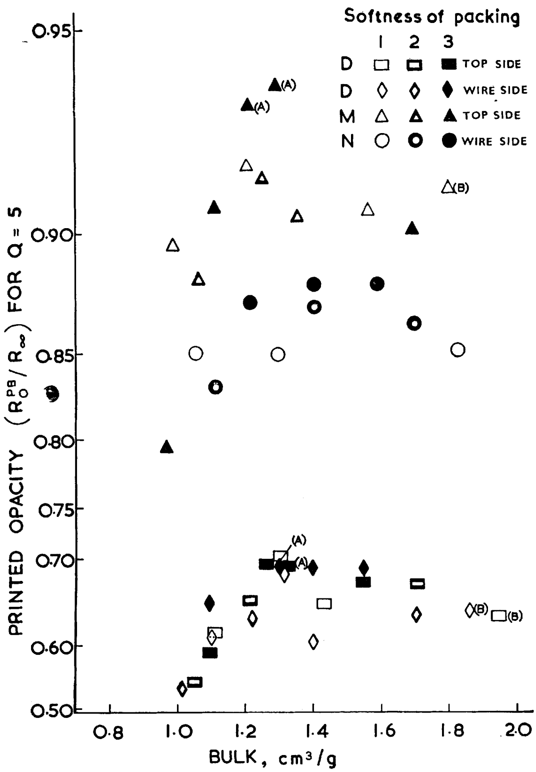


Fig. 9—Printed opacity of prints of standard quality compared with bulk for the three pressed webs—
A: sampled after supercalender
B: sampled after machine calender

Conclusions

By dry pressing webs, it is theoretically possible within limits to vary independently a considerable number of factors that might affect the printing properties of paper. These include—

1. Bulk.
2. The non-uniformity of bulk.
3. The non-uniformity of thickness.
4. Mean printing roughness.
5. The difference between top side and wire side roughness.

The results given by the factorial experiment in the current investigations can however be largely explained in terms of only two variables—

1. The degree of compacting of the paper web under the combined influence of pressure and moisture content.
2. The softness of the surfaces used to compact the web in relation to the compressibility of the web.

The effects caused by these variables differed somewhat from web to web, but the following relationships for each web were observed—

1. Scattering power, opacity, luminance, ink penetration index and print-through for a specified quantity of ink on the paper were all related to the degree of compacting of the web, as measured by bulk, but the mean values of these quantities were not influenced by the softness of the packing used in the hydraulic press.
2. Printing roughness measured by the guard ring instrument and an ink absorption index calculated from air permeability measurements were determined by both the bulk and the softness of the packing. Under some conditions, a soft packing limited the increase in smoothness that could be achieved. The amounts of ink required to achieve specified levels of print reflectance, quality or ink transfer were related to the roughness, absorbency or to the packing softness itself.
3. The uniformity of a number of properties were strongly affected by the softness of the packing, especially when webs were pressed to a low bulk. Soft packings tended to produce sheets of uniform bulk and roughness, but of non-uniform thickness and opacity. Print-through was also uneven. Paper pressed between steel plates was uniform in thickness and opacity, but non-uniform in roughness so that prints made on it were mottled. Print-through was uniform, although at low bulks, dark specks were caused by small areas of high substance that had been rendered translucent by the pressure (Fig. 3).

Although the non-uniformity of thickness over distances of a few millimetres did not affect the quality of prints made on webs pressed with soft packing, this may have been a consequence of the relatively soft press blanket that was used. A less compressible blanket might have given different results. The non-uniformity of thickness had a considerable effect on Bendtsen roughness.

The use of resilient materials for compacting paper webs appears to have certain advantages, but it is necessary when no slip occurs to match the resilience of the surfaces used for pressing to the compressibility of the paper web. Preliminary experiments on the combined effects of slip and pressure suggested that slip might modify this relationship between packing softness and the paper. The principal effect of slip was to increase gloss. In relation to bulk, only minor and somewhat erratic improvements in printing roughness were noted when the paper slipped over a polished steel surface.

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Appendix—Details of paper test and derived quantities

Substance, g/m^2	Calculated from weight and area of sample
Thickness, μ	The mean thickness of sheets measured eight at a time at 0.5 kgf/cm^2 pressure between 1.2 cm diameter parallel anvils
Bulk, cm^3/g	The ratio thickness/substance
Bendtsen roughness in absolute units, μ	Calculated from the air flow q ml/min at 150 mm w.g. for 1 kgf/cm^2 land pressure using the formula— Absolute roughness $= 1.545\, q^{\frac{1}{3}}$
Guard ring roughness, μ	Measured at 20 kgf/cm^2 mean land pressure with a 0.05 mm wide metering land: paper backed with the material used as cylinder packing on the Vandercook press—see Parker[5]
Air permeability, ml/min	Bendtsen permeability at 150 mm w.g.
Luminance	Estimated by means of the Elrepho reflectometer
Scattering power Absorption power	Calculated from luminance measurements using the theory of Kubelka and Munk as modified by Van den Akker (*Tappi*, 1949, **32** (11), 498)
Specific scattering coefficient, cm^2/g	Scattering power per unit oven-dry substance

All tests were performed in air conditioned to 50 per cent relative humidity and 20°C, except where otherwise indicated

Discussion

Mr J. D. Peel—The maximum normal pressures in the nips of a supercalender stack, calculated by means of Hertz's formula, do not increase more than about 25 per cent from top to bottom. In a machine calender, however, Mardon *et al.* (reference 5 in his paper at this symposium) show that these pressures probably increase four or five fold down the stack. Can either Parker or Mardon suggest why only one or two appropriately designed and loaded nips could not be used to achieve the same results now requiring very many more in these operations?

Mr J. Mardon—You have raised a good point. In the work on machine calenders with which I have been associated, it seems to have shown the actual smoothness to be a function of the number of nips, as it is appreciably dependent on the shear. It is difficult therefore to attain the required smoothness. One knows also that it is possible in supercalendering to spoil the smoothness by having too many nips.

I regard it a mistake to look for a universal printability index, because there is no universal pressman.

Dr A. B. Truman—Could I make a plea for consistency of terminology, not only in our own industry, but also between associated industries and, in particular, between the papermaking and printing industries. In Fig. 7, the expression *print-through* is used. In the printing industry (particularly letterpress), *print-through* may be used to denote the mechanical deformation of the sheet by the raised type in the printing nip of the letterpress machine, also called *impression* and not the optical effect described. The effect of ink vehicle penetration is usually referred to as *strike-through.* So far as I know, there is no term used to indicate the total effect produced by show-through plus strike-through.

Mr L. O. Larsson—In connection with Parker's paper, which brings into focus a very important use of paper, namely, the use of paper as a *print carrier*, I would like to mention an investigation in the same field carried out at the

Research Laboratory of the Swedish Newsprint Mills. The theme of this symposium does not properly allow us to discuss at too great a length the interesting phenomena of interaction between paper and ink in the printing processes. Yet, for the benefit of those interested, the investigation I referred to has been presented to the Eighth International Conference of the Printing Research Institutes in Finland this summer, also issued as a report from our laboratory under the title *Physical Interaction between Newsprint and Conventional Inks in Letterpress Printing* by L. O. Larsson and P. O. Trollsås.

It discusses the behaviour of newsprint in the letterpress printing process and the interaction between newsprint and a carbon black/oil ink. Results from investigations on the separation of oil from the ink and the opacity-reducing effect of the oil are presented. The ink distribution in the transverse direction of the printed sheet is indicated and the dependence of the *print-through* thereon and on the oil separation and on the consequent opacity reduction, as well as on the bulk of the paper, are discussed. The aim was also to find separately the contributions of carbon black and oil, the two main news ink components.

Parker's finding that an optimum degree of calendering for uncoated papers exists is supported by our results with newsprint. The explanation we found for it might differ a little from that given here today. Parker stressed the change in scattering coefficient upon calendering, but we found no marked changes in optical properties for newsprint. Nevertheless, the print-through as a function of the bulk exhibits a minimum. The print-through value for the pigment component alone decreases as a function of decreasing bulk (or, if you wish, increasing degree of calendering). This is mainly due to improved paper surface and lower ink requirement. By certain techniques in our investigations, however, marked variation in the oil separation was revealed. These two facts together explain the minimum of the print-through at a certain degree of calendering as a result of two effects working in opposite directions, namely, decreasing oil separation and increasing ink requirement with increasing bulk. The results consequently indicate that an optimum degree of calendering exists in this respect (that is, with respect to print-through).

Dr O. L. Forgacs—The question has again been asked why the opacity of papers made from mechanical pulps decreases with decreasing Canadian standard freeness, whereas the reverse is true of chemical pulps. This phenomenon was discussed by Lorås, Hauan & Brandel*. The difference between chemical and mechanical pulps can be understood qualitatively with the aid of the diagram in Fig. Z.

* *Norsk Skogind.*, 1964, **18** (2), 44–50

As increasing mechanical energy is applied to both types of pulp, the specific surface increases and the bonded specific surface of the papers they produce increases, with a resultant increase in tensile strength in both cases. On the other hand, the unbonded specific surface of the sheet decreases for chemical pulps, but increases for mechanical pulps. Since changes in opacity

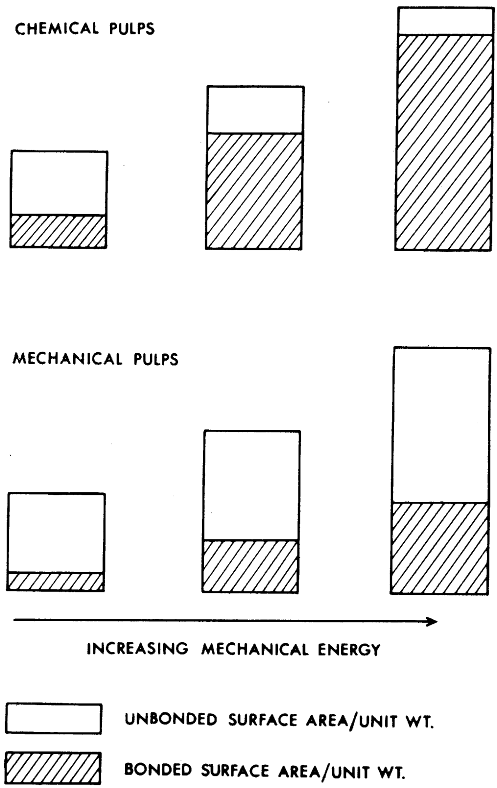

Fig. Z

with mechanical energy input are predominantly due to light scattering by unbonded surfaces, the difference in the behaviour between chemical and mechanical pulps becomes obvious. It is possible of course to produce pulps in the intermediate yield range that do not change in opacity with beating or refining. For such pulps, the increase in bonded area in the sheet is presumably equivalent to the increase in total specific surface of the pulps.

Mr J. R. Parker—I agree with Peel's and Mardon's comments on the possibility of using fewer nips in a supercalender.

Truman is confusing print-through with what is usually referred to as embossing or impression. Print-through, according to the *Glossary of Letterpress Rotary Printing Terms* (B.S. 3814: 1964), is the visible effect on the back of printed areas of show-through, strike-through or a combination of the two.

With reference to Mardon's comment on a universal printability index, I was speaking of an index that would predict the ranking of papers by a particular press, not to an index applicable to every type of press, regardless of its design or operating conditions.

I find Larsson's contribution very interesting, particularly his report of the effect of decreasing bulk upon the relative contributions of pigment and ink vehicle to strike-through. I have found that the printing pressure has a negligible effect upon the relationship between strike-through and ink weight on the paper. Strike-through increases appreciably with the time lapse after a print has been made with news ink. All these observations suggest that diffusion of oil through the paper makes an important contribution to strike-through, presumably because it fills some of the small interstices in the paper so that they scatter less light. Thus, a relationship between strike-through, scattering power and bulk is to be expected for a restricted range of furnishes.

Newsprint is not often calendered to a bulk less than 1.4 cm^3/g, so in practice the effect of calendering on its mean optical properties is seldom observed. Other grades of uncoated paper are calendered more heavily and, for these, the effect on optical properties should be appreciable.