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THE PRINTABILITY OF SYNTHETIC AND PLASTICS PAPER

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Synopsis A distinction is made between the two sheet materials named in the title and nine examples are quoted covering a wide range of both of them. A brief description is given of the method of producing such materials and surface micrographs at a magnification of 2 000 times are reproduced to show the wide difference in surface texture.

The physical test data for six of the synthetic and plastics papers are quoted in comparison with similar data for three conventional coated papers. In particular, the ink absorbency of plastics paper is far too low to permit the use of conventional printing inks that dry mainly by solvent absorption. The dimensional stability is exceptionally good and increases as the proportion of cellulose fibres in the sheet diminishes. Most plastics and synthetic papers suffer from a relatively low stiffness compared with conventional papers, but there is definite evidence that a 'second generation' of plastics papers is being designed to give greater stiffness by means of a multi-ply construction, in which the centure of the sheet has a low density honeycomb structure.

Generally, the plastics papers have a significantly higher resistance to the dissipation of static electricity than do conventional papers. The presence of mineral coatings considerably reduces the resistivity, as shown by some of the plastics papers that have had a surface coating. Contrary to expectations the consistency of quality of plastics papers is not better than that of conventional papers; in fact, it is often less consistent. Values of the coefficient of variation for some of the papers are given in the text.

In an appendix, a description of the physical characteristics of an unidentified Japanese second generation plastics paper are given. The plies had been separated by a manual technique and their varying grammage, thickness and density were determined.

Meanings

THE difficulty of defining the meaning of the term *printability* is familiar

Under the chairmanship of Dr J. A. Van den Akker enough to all who have worked in this field. It is usually taken to cover those aspects of paper performance that have an influence in the appearance of the final printed image. In the context of this paper, the broader view is taken that printability should also include many of those aspects of sheet performance that are more correctly described as *runnability*. Clearly, although

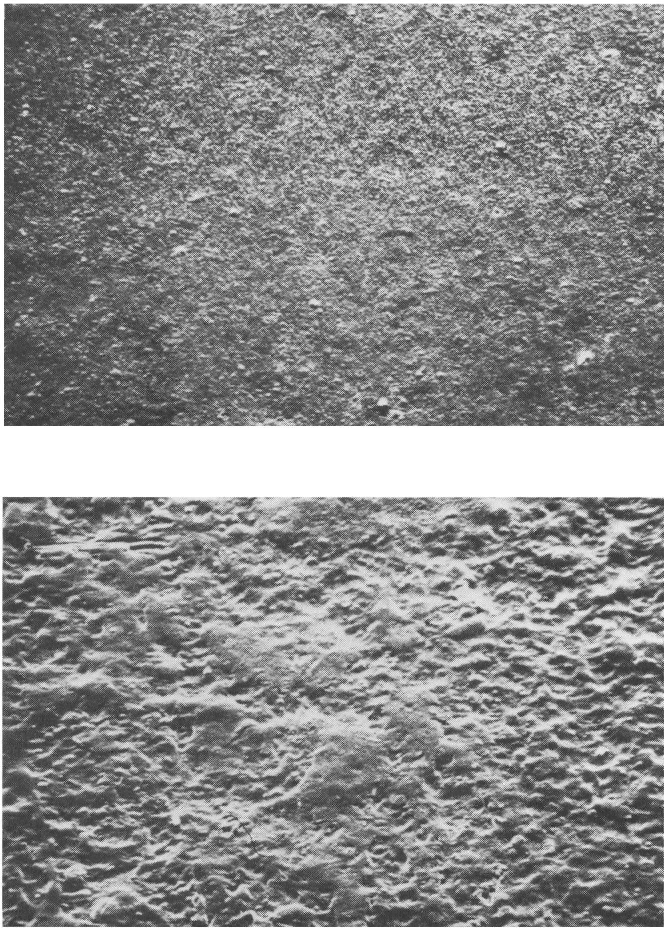

Fig. 1*—Polyart 115 g/m*^{2} A filled, biaxially oriented HDPE, the surface of which undergoes a special treatment
Note the surface irregularity, which bears some resemblance to coated paper
The photographs are of a printed surface
(Top × 100) (Lower × 2 000)

the appearance of the printed work is a most important factor in assessing the quality of a sheet material, the ease of achieving the desired standard of appearance under practical running conditions is at least of equal commercial importance and it would be wrong to ignore those physical attributes of the material being printed that govern the commercial attractiveness of the raw material and the end product.

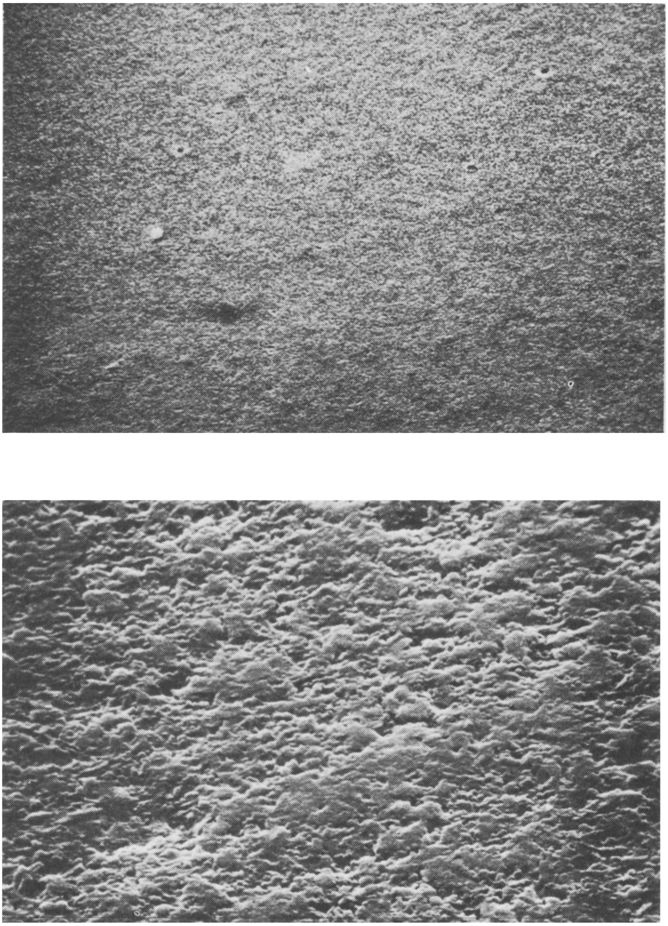

Fig.* 2—*Q-Kote synthetic paper type QC 150 A pigmented coated, specially treated film based on polystyrene
The surface has a smooth and glossy appearance
Note the similarity of texture to coated paper and Polyart
(Top × 100) (Lower × 2 000)

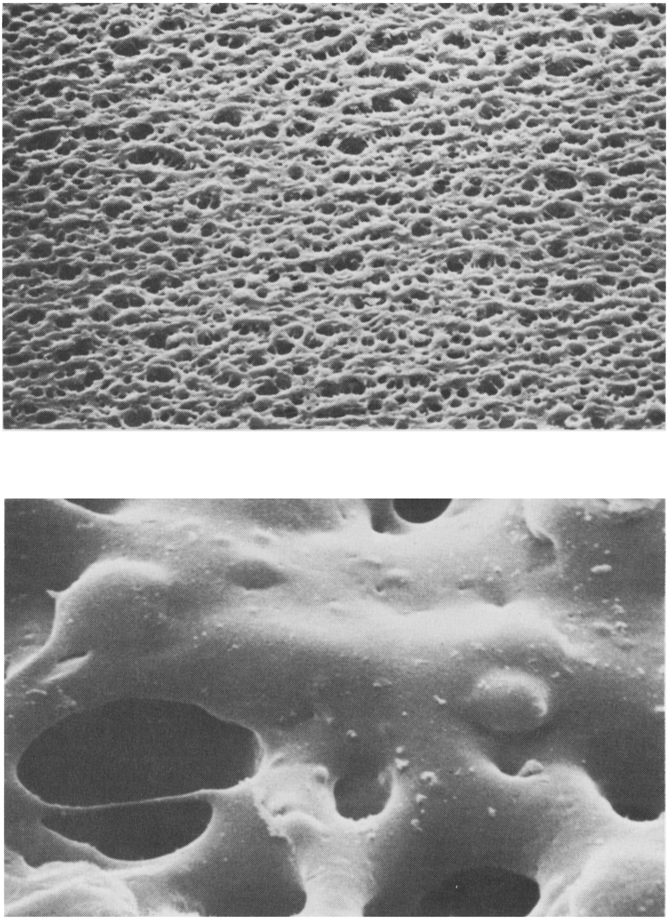

Fig. 3—Q-per synthetic paper type QM32 A polystyrene film, biaxially oriented and subsequently treated with a solvent
Note the unique pitted surface that results in porosity and improved reception of inks. The pitted nature of the surface results in a very approximate simulation of the highly magnified paper surface
(Top × 100) (Lower × 2 000)

We must now distinguish between those kinds of sheet material that are described by the term *synthetic paper* and those that are described by the term *plastic papers*.

We would define a synthetic paper as one in which an appreciable part of the furnish (at least 20 per cent) consists of synthetic fibres, alternatively one in which synthetic binders (such as latices) have been used to such an extent as effectively to constitute a forming medium for the sheet. The two grades of paper thus produced have substantially different physical properties and generalisations should be avoided.

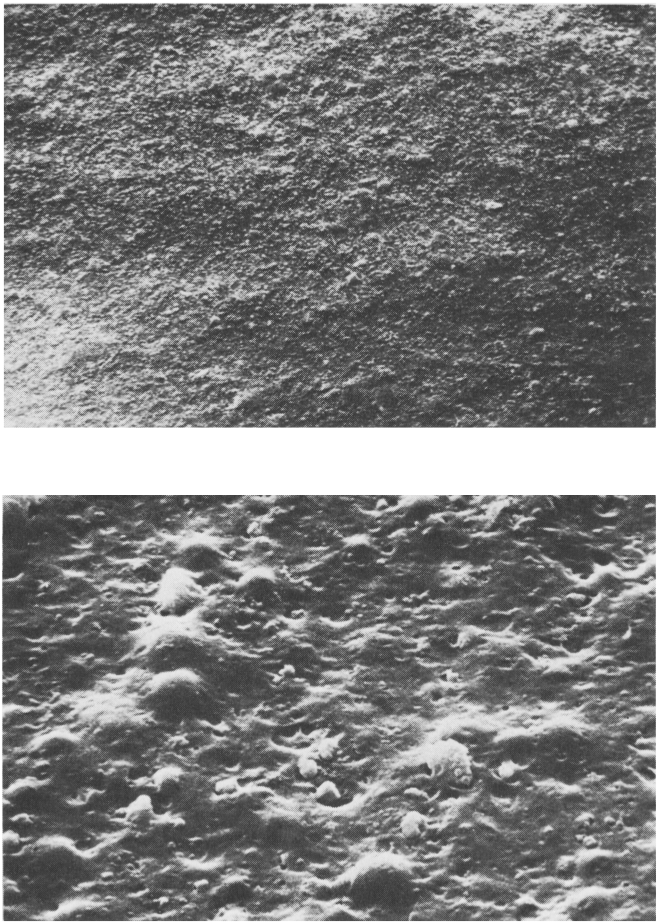

Fig. 4—Printel type S A synthetic paper based on polystyrene film
No details are available in the literature, but the company makes extensive use of techniques involving orientation and extraction of a soluble component
This technique is not apparent in the above photographs, which suggest the use of high filler concentrations: one gets the impression of filler particles breaking through the surface possibly as a result of biaxial stretching
(Top × 100) (Lower × 2 000)

Plastics paper is a flexible sheet material that has been manufactured by a process of extrusion, casting or any similar process not involving deposition from a suspension of particulate or fibrous matter in a carrying vehicle. The formed sheet may contain fillers such as are used in conventional papermaking operations and other additives; the sheet may be modified subsequent to manufacture by chemical or physical processes of it may be coated with material such as those used in conventional papermaking operations. The finished sheet has many of the sheet-like characteristics of paper and is often used in situations in which paper has traditionally been used.

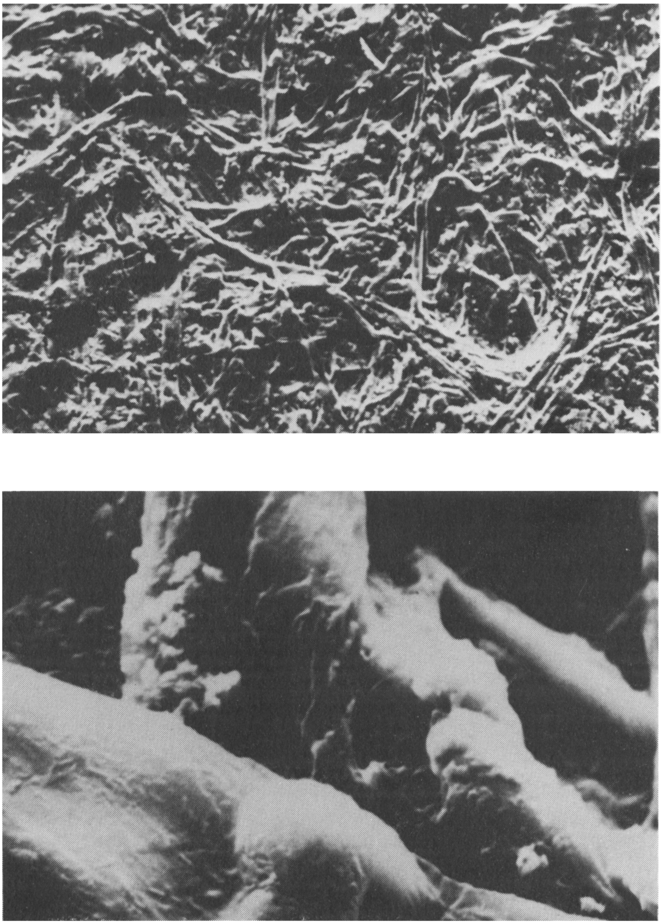

Fig. 5—Uncoated printing paper showing the fibrous structure
(Top × 100) (Lower × 2 000)

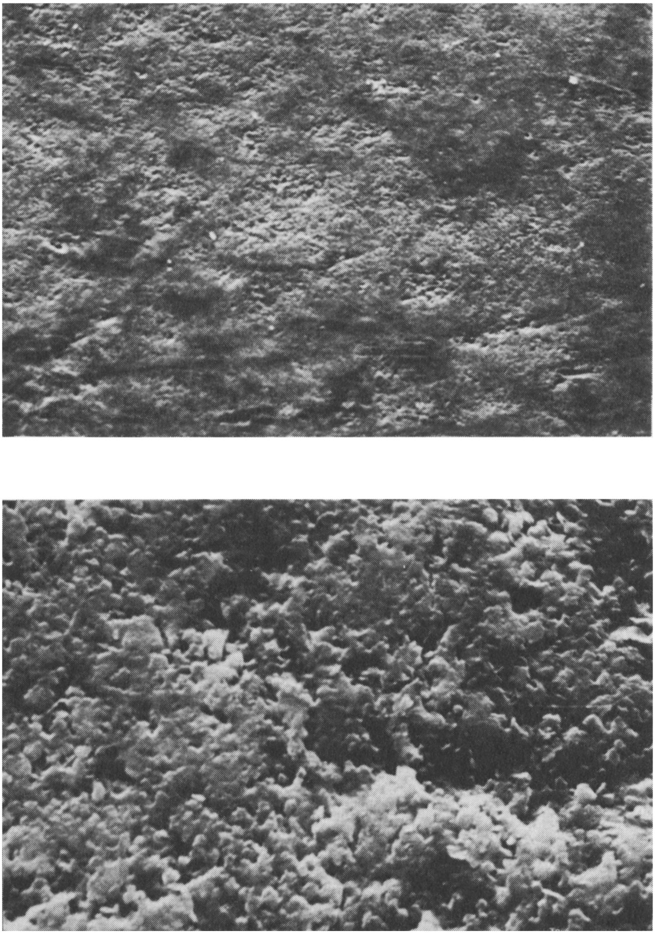

Fig. 6—Coated printing paper
Note absence of fibrous surface: it has a porous surface in which particulate filler is noticeable
(Top × 100) (Lower × 2 000)

As part of the work leading up to the Pira/RAPRA study,[1] a series of stereoscan surface micrographs of conventional and plastics papers was produced, some of which are shown in Fig. 1–6.

There is no such thing as a typical plastics or synthetic paper and a wide variety of both kinds of sheet material is now available, though neither could be said to have made a significant impact on the market for printing papers. Existing grades of both papers have a range of performance characteristics and basic properties that is as great as that existing among conventional papers and there would appear to be no limit to the development of a broader range of both types. The appearance on the scene of synthetic woodpulp, which may be included in a cellulose furnish to create papers that satisfy the definition of synthetic papers, further increases the potential range of products. Although very different from conventional paper in many ways and although much more costly in their present form, we must regard them as competitive to paper in many areas of end usage; that is the reason for their inclusion in this conference.

It would be useful at this point to list a few of the more familiar plastic and synthetic papers to indicate the range of products currently available.

TABLE 1—SOME SYNTHETIC AND PLASTICS PAPERS AT PRESENT AVAILABLE

Trade name	*Grade*	*Nature*	*Approx. U.K. price/tonne*
Polyart	Plastics paper	Filled polythene sheet	£750
Q-Kote	Plastics paper	Polystyrene sheet, coated	£900
Q-Per	Plastics paper	Polystyrene sheet with surface modified by solvent elution	£2 000
Tyvek*	Synthetic paper	Spunbonded polythene	£1 600
Ascot	Synthetic paper (coated Tyvek)	Spunbonded polythene, coated	
Texoprint*	Synthetic paper	Kraft fibres impregnated with latex	£950
SWP papers	Synthetic paper	Synthetic fibres Sheet formed using conventional papermaking processes	
Printel-S	Plastics paper	Polystyrene sheet surface treated, filled base	£1 000
Acroart	Plastics paper	High density polythene sheet, surface-treated, filled base	£1 200

* Brief notes on the method of production of these two types of product are given in Appendix 1: for similar information on the others, see literature references[1, 7]

Note—The coated papers considered in parallel with these plastics and synthetic papers cost between £320 and £500 per tonne

Appendix 1 to this paper contains a brief description of techniques used to modify the properties of some of these products, so as to produce a simulated paper effect. Further comments on the physical and chemical properties of these papers will be made during the course of this paper.

The search for a physical test routine that would adequately reflect the 'printability' characteristics of a sheet of paper has provided employment for many paper scientists over the course of the last twenty years and very little real progress has been achieved towards discovering this Holy Grail. In the course of this research and development work, most of the physical properties of paper have been related in some way to its printability and runnability characteristics, but it is true to say that certain properties of conventional papers are generally regarded as more important than others for assessing the printability characteristics of the sheet. One can therefore argue that it is reasonable to apply these same test methods to plastics and synthetic papers in lieu of an adequate printability test. This is a justifiable hypothesis, when one remembers that these new developments are being marketed in the main as replacements for existing papers and that they are being used in processes hitherto reserved for conventional sheet products. Therefore, one must start out at least by assessing them by the same criteria as those applied to traditional products. This we have done at Pira and some of the test data obtained on a limited range of synthetic and plastics papers are given in Table 2, alongside test results for conventional coated papers. (To aid comparison, all the data have been related to a sheet of 100 g/m^2 grammage.)

In an attempt to assess the broad printability characteristics of these new materials, we have chosen the following range of attributes as being the most relevant—

1. Surface roughness
2. Ink absorbency
3. Surface strength
4. Stess/strain characteristics
5. Dimensional stability
6. Stiffness
7. Generation and conductivity of electrostatic charge
8. Water absorbency
9. Consistency of quality

We would like to make the following comments on each of these properties.

Surface roughness

A WIDE range of results has been obtained, similar to what might be expected from conventional papers. One might argue that some of the plastics papers are more similar in their nature to uncoated papers and others are more similar to coated papers in relation to their surface properties. The surface permeability that has an influence on the test results is quite different in a paper such as Q-Per from that of either a plain paper or a coated paper. Whether one could assume that a sample of Polyart, which has virtually an identical printing roughness with that of conventional coated papers, would give the same print quality as a sample of coated paper is very questionable.

We included the Bendtsen test for surface roughness, because it is in common usage in most papermills, but we acknowledge the generally accepted fact that the Bendtsen test provides a poor indication of roughness under actual printing conditions. The introduction of plastics and synthetic papers into comparisons of surface roughness would seem to make the Bendtsen test even less valid than before and it emphasises the need to reproduce actual printing conditions more than ever when testing for roughness.

TABLE 2—PHYSICAL PROPERTIES OF SOME SYNTHETIC, PLASTICS AND CONVENTIONAL COATED PAPERS

Property	Units	*Synthetic and plastics papers* Acroart	Polyart	Printel-S
Apparent density	g/cm³	1·12	1·10	1·14
Tensile strength MD	kN/m	2·20	7·10	1·30
Tensile strength CD	kN/m	2·10	5·30	1·20
Tensile ratio MD/CD	—	1·05	1·34	1·08
Stretch-to-break MD	per cent	> 200·00	70·00	1·20
Stretch-to-break CD	per cent	> 200·00	120·00	1·80
Stiffness (B.S. 3748) MD	mN	1·90	3·40	1·40
Stiffness (B.S. 3748) CD	mN	2·40	3·40	1·40
Roughness—Bendtsen* (1 kgf/cm² pressure)	ml/min	28·00	8·00	20·00
Roughness—Printsurf*				
(10 kgf/cm² pressure)	μm	2·20	1·00	—
(20 kgf/cm² pressure)	μm	1·70	0·80	—
Opacity (B.S. 4 432, pt. 3)	per cent	88·00	93·00	88·00
Oil absorption* (SORT) (RTM 1)	s	> 300·00	> 300·00	—
Wet strength (by tensile strength)	per cent	88·00	103·00	—
Air permeability—Bendtsen	ml/min	< 5·00	< 5·00	—
Tensile yield point MD	kN/m	0·60	1·50	—
Tensile yield point CD	kN/m	0·55	1·50	—
Stretch at yield point MD	per cent	0·50	0·75	—
Stretch at yield point CD	per cent	0·45	0·85	—

* Mean of both surfaces except for Kromekote & Astralux (coated surface only)

Ink absorbency

THIS characteristic of conventional papers is a complex phenomenon that is still not fully understood and when discussing it in the context of plastics papers, as was the case for roughness testing, it would be unwise to draw firm deductions by analogy with the behaviour of conventional papers. Plastics papers that effectively are non-absorbent towards ink vehicles are being printed with inks rather similar to those used for metal foil. Some synthetic papers have structural characteristics more similar to conventional ones and are being printed with conventional inks. Thus, both the nature and the degree of the absorbency of ink vehicles into plastics and synthetic papers is quite different both one from the other and from conventional papers.

The only generalisation that can be made here is that for certain kinds of plastics paper the ink absorbency is far too low to permit the use of inks that dry mainly by solvent absorption.

Surface strength properties

THE resistance to picking of plastics papers and synthetic papers, excluding those made from a combined furnish of cellulose and synthetic woodpulp fibres, is very high. The fibre-to-fibre bonding of synthetic and cellulose fibres in those papers that we have so far seen is less than satisfactory and the resulting pick resistance has been very low. The pick resistance can be

TABLE 2 (*contd.*)

Synthetic and plastics papers				*Conventional coated papers*		
Q-Kote	*Q-Per*	*Texoprint*	*Tyvek*	*Ambassador*	*Astralux*	*Kromekote*
1·25	0·57	1·25	0·48	1·15	0·92	0·98
3·40	2·50	3·50	6·70	4·10	6·70	3·90
2·90	2·10	2·30	5·70	2·20	3·30	2·50
1·17	1·19	1·52	1·17	1·86	2·03	1·56
10·00	35·00	4·90	35·00	3·10	1·70	1·30
16·00	10·00	12·00	35·00	6·90	5·30	5·10
2·20	4·20	2·10	10·40	4·20	9·10	6·20
2·00	3·20	1·10	9·00	2·90	6·00	3·90
6·00	200·00	61·00	600·00	17·00	16·00	10·00
0·90	4·80	2·30	5·10	1·00	0·90	0·80
0·80	4·30	1·60	4·20	0·80	0·80	0·70
95·00	75·00	92·00	98·00	98·00	94·00	95·00
> 300·00	< 3·00	< 300·00	> 3·00	27·00	80·00	290·00
91·00	—	36·00	—	6·00	4·00	17·00
< 5·00	5·00	> 5·00	500·00	8·00	13·00	5·00
0·87	—	1·10	—	1·50	4·10	2·70
0·93	—	0·32	—	0·67	1·30	0·93
0·55	—	0·50	—	0·55	0·65	0·60
0·60	—	0·40	—	0·45	0·40	0·40

improved during manufacture by surface heat treatment at a calender stack (or otherwise), but usually at the expense of other properties.

Plastics papers should be relatively free from problems associated with linting, dusting or fluffing. We have noticed, however, a tendency with a number of plastics papers supplied in sheet form for slivers of the plastic material to be trapped between adjacent sheets and this problem is aggravated by the high levels of static electricity sometimes present in plastics papers.

To obviate difficulties arising from low ink absorption and slow drying with plastics papers, it is possible to use surface coating treatments that involve the presence of mineral powders. The reinforcing effect that is provided in conventional papers by fibres protruding from the sheet into the coating is not available of course in plastics papers and this could lead to a tendency for coating pick.

Stress/strain characteristics

A COMPARISON of the charactesistics of plastics papers and conventional papers is shown in Fig. 7 & 8. It can be argued that paper normally shows no such thing as a true yield point on its stress/strain curve, but many papers show a portion of the curve at which the slope has a pronounced change and it is not unusual for this point to be regarded as the commencement of the 'yield' phase. The yield point for plastics papers is usually much more pronounced. The performance of plastics papers is very similar to that of conventional papers in the cross-direction up to the yield point. This has some importance to the printer, since such printing problems as misregistration, backedge stretch and tail end hook are often related to the stress/strain characteristics at subcritical loads. Whereas a choice may be available for the sheet-fed printer of paper cut long or short grain, no such choice is available in plastics paper, which is in effect all 'long grain'.

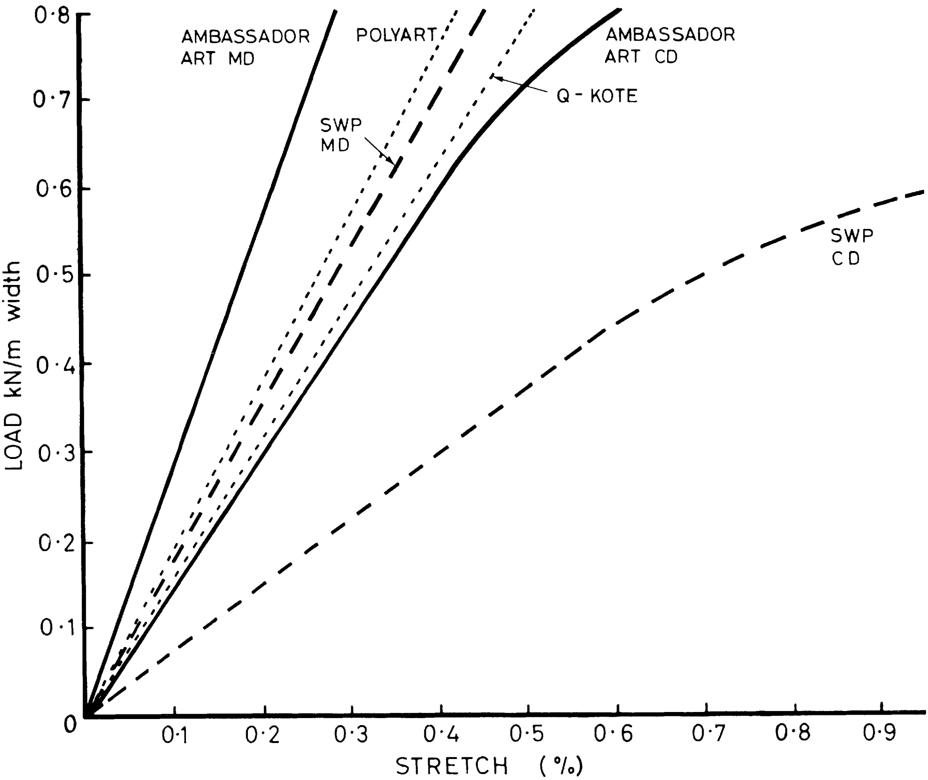

Fig. 7

In general, plastics papers have a high tensile strength and a high stretch to the rupture point. For some materials, the latter quantity may exceed 100 per cent, but this is of little consolation to the printer and the properties of the sheet after the yield point are hardly relevant to printing applications, either in their own light or compared with conventional papers.

Dimensional stability

As MIGHT be expected, the stability of synthetic and plastics papers in the presence of water improves as the proportion of cellulose fibres diminishes.

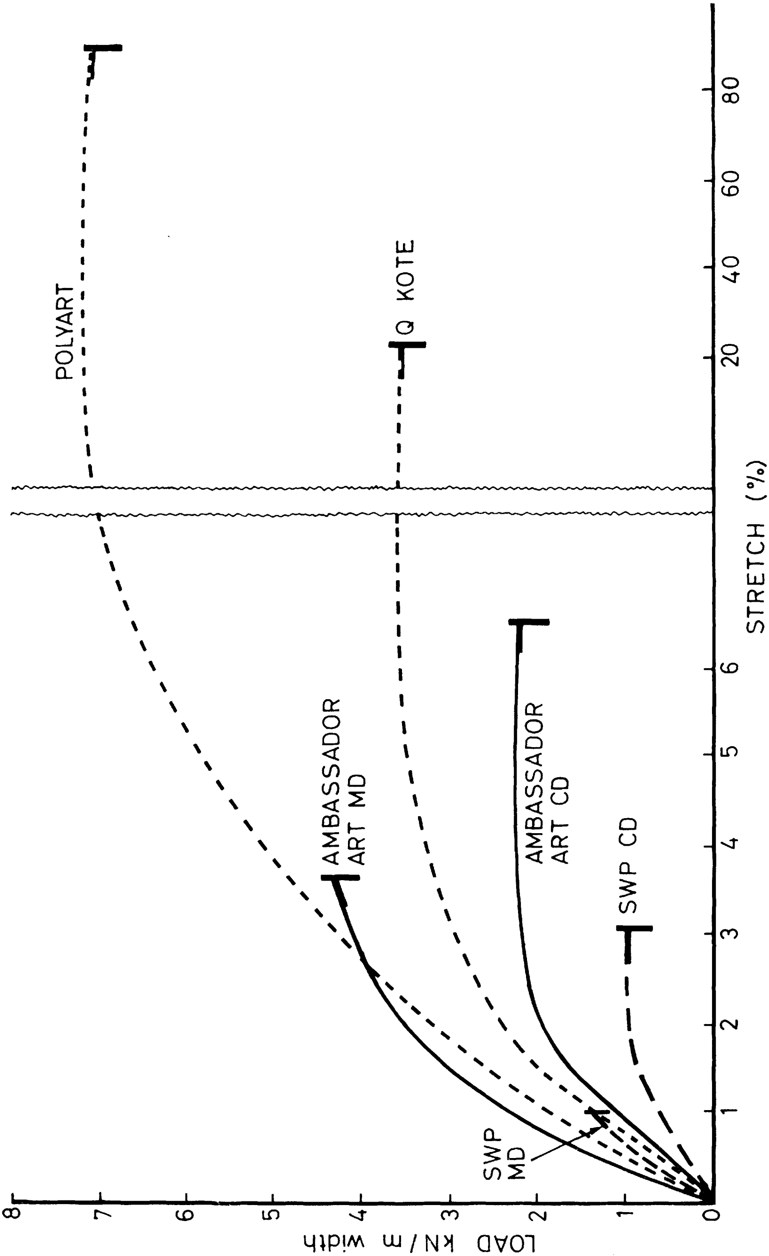
LOAD kN / m width
0
1
2
3
4
5
6
7
8
STRETCH (%)
1
2
3
4
5
6
20
40
60
80
POLYART
Q KOTE
AMBASSADOR ART MD
AMBASSADOR ART CD
SWP CD
SWP MD

Fig. 8

We have to consider, however, some unusual effects of heat and of organic solvents on plastics papers, which are less stable in this respect than conventional papers.

Organic solvents, including some of the solvents present in printing inks, may be absorbed by plastics papers, giving rise to changes in dimensions and physical properties. Swelling and distortion of heavily printed areas have been observed. It would appear that specially prepared inks will be needed for such papers, especially those based on polystyrene and it will not be possible to use conventional quick-drying inks.

Distortion due to heat can also occur. The molecular orientation that takes place during the manufacture of plastics papers can be partially reversed by a relatively mild heating. Shrinkage and distortion may occur during the drying of heat set inks and ultra-violet cured inks, also as a result of the heat produced during the oxidation drying of inks. These effects are aggravated by the poor thermal conductivity of plastic, since the localised heat does not dissipate quickly. Thus, it will not be possible to use such papers under certain conditions that with conventional papers now give rise to no such problems.

Stiffness

MOST plastics papers and some synthetic papers suffer from a relatively low stiffness compared with conventional coated and uncoated papers. This is less satisfactory, partly because of the lack of acceptability of the products to the ultimate consumer.

The low stiffness of these materials during printing is aggravated by the higher levels of static electricity frequently encountered. Feeding from the stack becomes more difficult and delivery of the printed sheet needs to be more carefully controlled so as to avoid the subsequent difficulties inherent in knocking up a stack of sheets of low stiffness.

There is some evidence that the second generation of plastics papers are being designed to give greater stiffness by means of a multi-ply construction, in which the centre of the sheet has a low density honeycomb structure.

Effects of static electricity

THERE are two aspects of this problem that need to be considered. The generation of static electricity by a sheet of 'paper' on a printing press is related to the construction of the sheet and the nature of the surfaces with which it comes into contact. The tribo-electric series (Table 3) gives some idea of the relative size of charge that will be generated by different materials in contact with one another. It will be seen that, although cellulosic paper passing over a steel roller will acquire a smaller charge than would a plastics paper on a similar roller, the order of magnitude of the charge might be reversed if rubber-covered rollers were involved. Yet a steel roller should discharge its static charge more readily to earth than would a rubber roller and will therefore continue to generate a charge in web or sheets passing over it, whereas the rubber roller may not conduct its charge to earth and will therefore have a reduced charge-generating effect on the web or sheet.

TABLE 3—PART OF TRIBO-ELECTRIC SERIES

Asbestos	*Acquire a more positive charge*
Nylon	
Wool	
Aluminium	
Paper	
Cotton	
Steel	
Hard rubber	
Rayon	
Brass	
Synthetic rubber	
PVdC	
Polythene	
Teflon	
Silicone rubber	*Acquire a more negative charge*

Tribo-electrification is the separation of charges through surface friction. The further apart in the series the materials are located, the more readily is the static charge generated. The materials at the top of the scale acquire a charged positive with respect to those lower down.
The charge generated will depend on many factors, including closeness of contact and rate of separation.

The rate of dissipation of a static charge in a sheet of conventional or plastics paper is strongly affected by its resistivity and some data on the surface resistivity of plastics papers compared with coated and uncoated papers in given in Table 4. These values were obtained at Pira, using the method given in B.S. 3880.

The presence of mineral coatings considerably reduces the resistivity, as is shown by the comparison between the plastics papers Q-Per and Q-Kote. The resistivity of conventional papers clearly depends to a large extent on any ionic constituents present and some very high purity papers have a resistivity comparable with plastics papers, but the plastics papers generally have a significantly higher resistivity than conventional papers. It is useful to note that a maximum resistivity of $3{\cdot}5\times10^9$ ohms per square is often specified for papers to be used for high speed data processing machines to minimise problems arising from static generation.

It follows from the above comments that generalisations about the magnitude of static problems when using conventional or plastics papers are unwise.

Much depends on the design of the printing press, the material used both in the papers and the surfaces with which the papers come into contact. The moisture contents of the materials and of the ambient atmosphere, also the nature of the fluids used in the printing process will have some effect. It seems probable that at high printing speeds, however, plastics papers and synthetic papers containing a high proportion of synthetic woodpulp when running in contact with metallic surfaces will be liable to acquire larger charges than will conventional papers and to dissipate the charges more slowly.

TABLE 4—SURFACE RESISTIVITY AT 23° C & 50 per cent rh

Acroart	greater than	10^{12} ohms/square
Polyart	greater than	10^{12} ohms/square
Q-Per	greater than	10^{12} ohms/square
Q-Kote	approximately	7×10^{10} ohms/square
Tyvek	approximately	5×10^{9} ohms/square
Texoprint	approximately	2×10^{9} ohms/square
Typical coated papers	approximately	$1-5\times10^{9}$ ohms/square
Typical uncoated papers	approximately	$1-50\times10^{9}$ ohms/square

Water absorption

SOME plastics papers currently on the market have a negligible water absorption and this has been shown at Pira and elsewhere[2, 4] to lead to difficulties in the offset lithography printing process. One function of conventional paper that is rarely taken into account is to absorb sufficient water on the litho press to maintain a satisfactory ink and water balance—that is, the paper acts as a buffer in facilitating the dynamic control of the system. When printing plastics papers on a litho press, the amount of water used has to be reduced to a very low level because of the low absorbency of the sheet, otherwise water droplets appear on the surface and a consequential snowflaking effect results in the printing image. At such a low water level on the press, control of the ink/water balance becomes much more difficult.

Consistency of quality

MUCH emphasis has been placed by the paper industry in recent years on improving the consistency of quality as an aid to better performance on the printing press. The evidence we have collected so far shows that the consistency of quality of plastics papers is no better than that of conventional papers and is often worse. Table 5, compiled from data obtained at Pira by Munday[9] gives values of the coefficient of variation for some of the range of cellulosic and plastics papers described in Table 1.

TABLE 5—VARIABILITY OF SOME SHEET PROPERTIES (PIRA DATA)

	Coefficient of variation, per cent				
Paper	*Grammage*	*Thickness*	*Stiffness*	*Roughness (Bendtsen)*	*Tensile strength*
Plastics papers					
Acroart	5·0	4·2	7·9	14	—
Polyart	6·2	8·1	6·5	13	5·5
Q-Kote	2·5	5·0	5·0	15	2·3
Texoprint	1·1	2·5	6·5	16	3·1
Conventional papers					
Ambassador	1·3	1·1	3·0	27	4·6
Astralux	1·1	4·0	4·8	17	3·3
Kromekote	2·9	2·7	4·9	45	6·6

Ghosting of prints

BECAUSE of the obvious limitations on the use of heat for ink drying on plastics papers, there may be a tendency for the dryer content in printing inks to be increased. The effect of these and other ink components, also the gaseous products of oxidative drying, when trapped by sheets of paper in a stack in a first printing pass, can be to give rise to a form of ghosting on the reverse side of the print when second or subsequent passes are made on the same sheets. The ghosting is caused by the transmission of noxious chemicals through the sheet or from sheet to sheet and is not usually obvious on the unprinted sheet. Ghosting of this type may be regarded as a phenomenon depending to a very great extent on ink formulations, paper properties and press room practices. It is difficult to predict the tendency of a sheet to cause ghosting by any simple tests, but it might be expected that ghosting would be increased when printing synthetic and plastics papers.[4, 6]

Printing experiences

THE most complete reports on the printability of plastics papers in the literature have related essentially to trial runs. Pira[1, 2] has printed six different plastics and synthetic papers on reasonably long runs, three of the papers on each of two separate occasions, using a sheet-fed offset Waite & Saville press. Most of the difficulties that have been mentioned in the preceding paragraphs, peculiar to plastics papers, were in fact encountered, although the quality of the printed image was generally excellent.

Gramlich[3] has given a full account of an experimental run using Celestra-Kote. The run was on a web-fed Harris-Cottrell M1000 offset litho press and very good printed quality was obtained. Yet, even on this relatively easy-to-print plastics material, some problems were experienced. Gramlich concluded that the material could be run on web offset presses if the ink drying characteristics, web tensions and web temperatures were accurately controlled.

Ridyard[4] has reported a trial on a four-colour Ronald Rekord sheet-fed offset litho press using Polyart. Most of the problems that occurred during this commercial run were related to ink drying and ghosting. Ridyard also reported on a long run of Q-Kote, when the only problems encountered were due to damaged paper and to static. He has also carried out short printing runs on Tyvek.

A number of general articles on the subject of plastics paper printability have been published, although they generally lack detailed case histories. Williams & Bisset[6] have considered this subject in some depth from the viewpoint of the ink manufacturer.

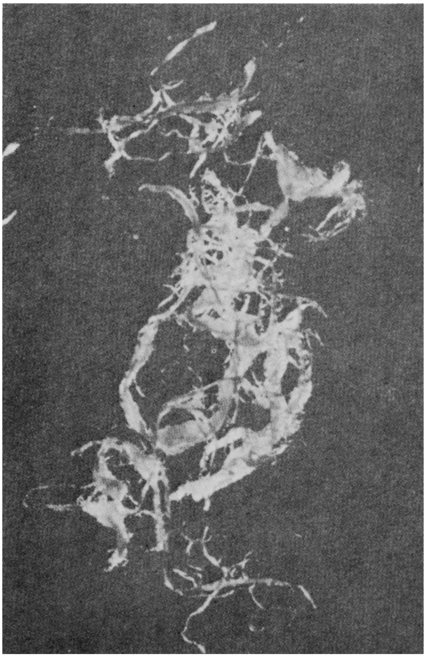

Fig. 9—Synthetic woodpulp (Magnification $\times 25$)

Future developments

DURING the course of a joint conference between the Plastics Institute and the British Paper & Board Makers' Association in London, May 1973, the viewpoint was expressed a number of times that large-scale penetration by existing plastics and synthetic papers into the bulk printings field was unlikely, if only for economic reasons. There are two new developments that cause a reappraisal of the situation—

1. The development of 'second generation' plastics papers with structural modifications that give a higher yield per kilogram and improved physical properties. Such a paper was recently examined at Pira and the results are given in Appendix 3.
2. The manufacture and introduction of synthetic woodpulps (SWP) on a commercial scale. Such pulps can now be obtained from a number of sources in North America, Europe and Japan; they are meant to be used in conjunction with conventional cellulose pulps in the ratio of about 30:70.

Barton(5) has described the technology of these fibres and in particular of the synthetic woodpulp developed by Crown Zellerbach. This material closely resembles natural wood fibres in many ways and is shown in Fig. 9. Samples of paper made with the Crown Zellerbach pulp have been tested at Pira and the resultant papers have been very similar in many of their properties to conventional papers, up to a proportion of 50 per cent SWP in the furnish. The lack of internal bonding strength of SWP to cellulose fibres results in a relatively weak sheet, which may be expected to manifest itself on the offset litho press by poor resistance to pick and an increased tendency to fluffing or linting. Printing trials carried out in Japan have revealed a very good printability property for SWP papers and tests carried out at Pira have shown that such papers behave similarly to uncoated conventional papers in the printing press. Special effects can be obtained by utilising the thermoplastic properties of the polythene fibres, which fuse at about 130° C, although the problem arising from broke repulping has not yet been overcome.

Whether or not synthetic woodpulps will play a large part in the future development of the paper industry depends on the answers to a large number of socio-technico-economic questions. The tonnage at present available is less than 10 000 per annum, mainly from Japan, although one company is planning a modest production unit in Europe.

Appendix 1

THE main body of this paper has been concerned with those aspects of plastics and synthetic papers that affect their printability and runnability characteristics. It is considered to be desirable, in view of the novel nature of the materials discussed, to devote an appendix to describing some of the techniques utilised for modifying the characteristics of the basic sheet in order to make it more suitable for use as a paper replacement. Further information is contained in the references cited previously, particularly in the report prepared by Pira and RAPRA on plastics papers.(1)

On the assumption that it is desired to make a plastics paper similar in properties to conventional papers, in order to market it as a substitute sheet material for printing purposes, attention must be paid to the following five aspects of the sheet structure—

1. Surface characteristics
2. Stress/strain properties
3. Stiffness
4. Generation and discharge of static electricity
5. Optical properties

The way in which some of these properties have been modified during the manufacture of plastics paper is described below.

Surface characteristics

These may be altered by at least four techniques—

(*a*) Corona discharge, which can provide a sheet surface that is receptive to inks. It is thought that Polyart is treated in this manner.

(*b*) A mineral coating may be applied to plastic sheets in a similar manner to that used for conventional papers. As was pointed out in the main body of the paper, there is a danger of low interfacial adhesion between the sheet and the coating, arising in part from the absence of surface fibres. Yet there appears to be no fundamental reason that almost any desirable surface structure could not be produced in this manner. An example of such a paper is Q-Kote, which appears to have a conventional coating.

(*c*) A large amount of filler material may be incorporated in the plastic resin during manufacture to give improved surface characteristics. There are clearly going to be limitations on the proportion of fillers, as with conventional papers, caused by the possibility of dusting in the offset litho press.

(*d*) Several other techniques have been used to provide an absorbent and ink-receptive surface. A complicated solvent elution procedure is used to prepare the ink-receptive surface of Q-Per paper. Other methods include the use of solvents to attack the surface, chemical oxidation, exposure to open flame and mechanical treatments such as sand blasting.

Stress/strain properties

The stress/strain properties of plastics sheets can be considerably modified during manufacture by 'orientation'—that is, by stretching the polymer so that the random polymer chains are forced to align in a regular way.(1)

Polymers such as polypropylene and high density polythene (HDPE) show a degree of crystallinity depending on their chemical structure.Some polymers can be manufactured with different stereoisomers, some of which are regular in form and conducive to crystal formation. This structural property is termed *tacticity* and the most regular form leading to high crystallinity is the isotactic form.

The physical forces in the crystal are greater than those between the uncrystallised polymer. Thus, the more crystalline or oriented the polymer, the stiffer it is (Fig. 10).

Orientation and the resulting crystallinity will also prevent molecules sliding or uncoiling. This is best demonstrated by looking at the fibre formation in polypropylene. If a tensile load is applied to a monofilament, it will yield and stretch until a high degree of orientation and crystallinity is obtained; then, on further loading, very little yield takes place until the material fractures (Fig. 11).

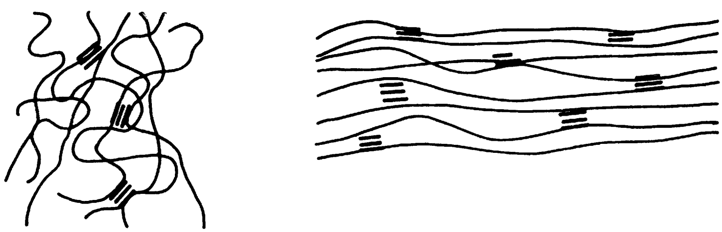

Fig. 10—Effect of orientation on crystallinity

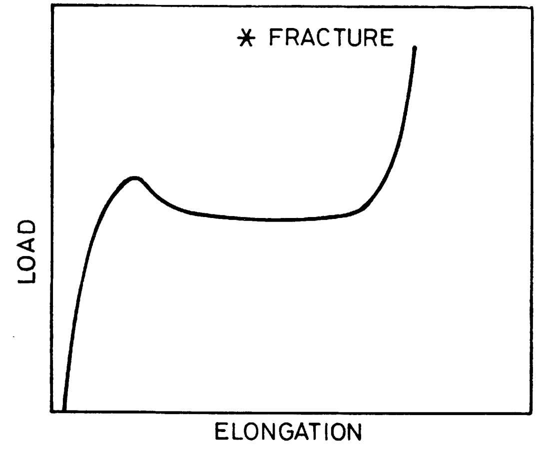

Fig. 11—To illustrate yield and crystallisation

Polymeric sheet can be similarly oriented during manufacture. Film extruded through a sheet die can be stretched in directions parallel to and normal to the line of flow. It is drawn longitudinally by drawing off the film at a rate greater than the linear delivery from the die. Stretching latitudinally is achieved by movement of grips at the edge of the film.

Biaxially oriented sheet is stretched in the two directions as indicated above, whereas uniaxially oriented sheet is usually drawn only in the direction of extrusion flow.

Alternatively, biaxially oriented sheet can be made by a carefully controlled blown film process, whereby the orientation normal to the line of flow is obtained by blowing the bubble. Further orientation is achieved by inflating the film a second time after the nip rolls.

Stiffness

The type of plastics material used and the degree of 'otientation' will have a considerable effect on the stiffness of the plastics paper for the reasons given in the previous section. This is confirmed by the following figures, which give relative stiffness at constant thickness, as an index—

Unoriented plastics		*Biaxially oriented plastics*	
High impact polystyrene	2·4	General purpose polystyrene	3·5
High density polythene	1·0	High impact polystyrene	3·0
Polypropylene	1·2	Polypropylene	3·0
Polyvinylchloride	2·5	Polyvinylchloride	3·4

Conventional papers 4–10
(The above table of stiffness is based on data given by Scott & Dobbinson[7])

It is well known that the most effective way of improving the stiffness of the sheet of a given grammage is by increasing its bulk. Ranger[8] has provided a simplified mathematical treatment that is useful in the present context.

For a homogeneous material of constant grammage, stiffness will vary inversely with the square of the density. For the more complex structures, it can easily be shown that optimum stiffness is provided when the lower density components form the core of the material.

Calculations for the stiffness of plastics sheets at constant grammage give the following results—

Plastic sheet	*Relative stiffness*	*Relative thickness*
Homogeneous sheet with density 1	1·0	1·0
Sheet with sandwich structure— 50 per cent of weight forming core of density 1; 50 per cent of weight forming surfaces of density 0·33	2·6	2·0
Sheet with density 0·5	4·0	2·0
Sheet with sandwich structure— 50 per cent of weight forming core of density 0·33; 50 per cent of weight forming surfaces of density 1	6·8	2·0
Homogeneous sheet with density 0·33	9·0	3·0

An interesting example of a plastics material with a low density surface structure is Q-Per. Although it is stiffer than other plastics sheets of the same grammage, it is less stiff than would be anticipated from a consideration of its mean density. The explanation for this is that the low density component of the sheet is in the wrong place in the sandwich structure. Although it is clear from theoretical considerations that a low density core surrounded by a higher density surface structure is the best way to get high stiffness from any sheet material, one must not forget the end usage of the material, in particular the danger of causing structural collapse of a low density region in the sheet by the pressures inherent in the printing and writing processes. It may be necessary to sacrifice part of the theoretical attainable density of a multi-layer sheet in order to get desirable absorbency properties on the surface and possibly to provide a lower risk of structural collapse.

The internal structure of a plastic sheet may be modified in a number of ways. For instance, materials may be incorporated into the resin that will produce gaseous products, either during sheet formation or immediately afterwards; this results in a cellular or expanded structure.

The use of incompatible materials that will tend to separate during extrusion or later processing should also be mentioned. 'Orientation' of a sheet by stretching may also cause structural changes.

Static electricity generation and discharge properties

There appear to be a number of papers being made in which proprietary chemicals are added to the sheet with the objective of increasing its conductivity, but no details are available. When setting out to solve static generation problems by chemical treatment of the sheet, one has to bear in mind the possibility of the chemicals migrating from the sheet to the surface or even into the fountain solution of a litho press and possibly giving poor printing conditions.

Improvement of opacity

The processes of biaxial orientation and structural modification already mentioned have the effect of improving the opacity of a sheet of plastics paper. Coating is also resorted to, often utilising the same materials and processes as are used in conventional paper coating. Fillers may be incorporated into the plastic sheet such as Polyart and this is probably the most economical way of imparting opacity.

Appendix 2—*Production of saturated and spunbonded papers*

Latex-saturated (Texoprint)

In the manufacture of Texoprint, bleached kraft fibres are formed on the Fourdrinier machine into a low density absorbent sheet. The base sheet is then saturated with elastomeric polymer latex and opacifying fillers. Here, the sheet picks up 60 per cent of its own weight in dry solids.

Following the saturating bath, the sheet is run through squeeze rolls, which squeeze out any excess latex. The sheet is then dried to control its moisture content.

After saturation and drying, the impregnated sheet is coated on both sides with printing fillers and a flexible latex binder. The composition of the coating is titanium dioxide, clay and elastomeric binders.

Texoprint's final finish results from supercalendering the coated sheet to bring out the levelness and gloss required.

In its final form, Texoprint is claimed to have exceptionally good dimensional stability together with a uniform caliper across the sheet.

Production of spunbonded materials (such as Tyvek)[10]

The first step in this process of manufacturing a sheet material is conventional melt spinning, in which a raw material such as polymer chips is extruded through a spinneret, drawn off and stretched either mechanically or aerodynamically.

Using various handling techniques, the individual filaments are carried to a web-forming zone, where they are deposited as a random web on a moving screen, through which the surplus air is drawn off.

In terms of web quality, a high degree of separation and absolute random arrangement of filaments is possible. Webs of 10–1 000 g/m^2 can be manufactured and these webs must then be subjected to one of the sheet-bonding processes. They can be chemically bonded, thermo-fused, heat sealed or even needled. The choice of different raw materials for the process and the selection of one or more bonding systems for the web permits a large number of variations in sheet properties. Despite their differing external appearances, all spunbonded sheets have common characteristics: they consist of continuous filaments arranged randomly in the XY plane. Because of this random arrangement of continuous filaments, spunbonded sheets exhibit very high tearing strength in every direction.

Because of the low wet strength of the conventional cellulose sheets, an ideal use of spun-bonded webs is as a component providing strength properties in combination products—that is, products consisting of a spunbonded scrim laminated between two layers of tissue paper, giving the material great wet strength plus high water absorption and soft feel. Products of this type are already widely used in the medical field.

***Appendix 3**—'Second generation' plastics papers*

A SMALL unidentified sample* of a material described as 'the latest plastics paper from Japan' was examined recently by Pira.

The plastics paper had a layered structure, the outer layers being distinctly different from the core. Filler was present in the outer layers, but not in the core. The plastics used in both core and surfaces was identified as polypropylene.

Test data

Total grammage		67 g/m²
Thickness		82 μm
Density		0·83 g/m³
Tensile strength*	MD	18 kN/m width
	CD	9 kN/m width
Tensile ratio	MD/CD	2·0
Stretch	MD	27 per cent
	CD	> 100 per cent
Stiffness*	MD	9·5 mN
	CD	6·2 mN
Bursting strength*		150 kPa
Bendtsen roughness		< 5 ml/min
Printsurf roughness		(10 kgf/cm²) 1·5 μm
		(20 kgf/cm²) 1·1 μm
SORT		≫300 seconds
Air permeability		< 5 ml/min
Surface characteristic		Not water absorbent
Ash		23 per cent

* On 100 g/m² basis

The layers were separated manually and their grammage, thickness and density determined.

	Surface 1	*Core*	*Surface 2*
Grammage, g/m²	17·0	31·0	20·0
Thickness, μm	18·0	41·0	22·0
Density, g/cm³	0·93	0·76	0·91

Bearing in mind that the density of polypropylene is close to 0·90 and that the fillers present would normally be expected to increase this substantially, the low mean density of the material (0·83 g/cm³) is particularly interesting. The density of the core is well below that of polypropylene. Photomicrographs (Fig. 12 & 13) show clear evidence of both open and closed cavities, which could have resulted from 'expanding' techniques. The tensile properties and ratio indicate a high degree of axial orientation, supported by the behaviour of the material when torn. The surface was very highly bonded, with virtually no filler present at the actual surface. The stiffness of the material was as high as that of conventional coated papers, as would be anticipated from its low density.

The appearance and properties of this material indicate that complex and sophisticated manufacturing processes must have been used, producing a sheet markedly superior in many ways to those previously examined.

* The material was probably Oji-Yuka Yupo FP Art paper

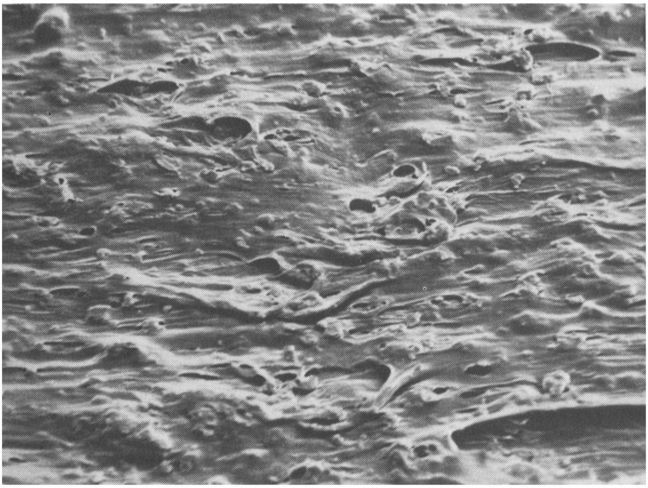

Fig. 12—Surface of 'second generation' plastics paper
(Magnification ×2 100)

Fig. 13—Section of 'second generation' plastics paper
(Magnification ×700)

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* Paper given at the Plastics Institute/BP & BMA International Conference on Plastics & Paper, London, May 1973

Transcription of Discussion

Discussion

Mr G. F. Underhay I believe that, in our printability discussions, we have rather forgotten some of the good work that was done 10 or more years ago. I would like to refer especially to a paper by G. L. Larocque (*Pulp & Paper Mag. Can.*, 1967, **68** (1), T16) of the *New York Daily News* and formerly of PPRIC. Gerry was very down to earth and, as I remember his conclusions, he hardly mentioned things like tear, tensile and burst. Instead, based on 20 years of detailed records, he showed that satisfactory runnability was linked with good stretch characteristics, better winding, higher moisture content, minimum roll damage and low shive content (consequent upon improved shive removed facilities in the papermills). Thus, he moved substantially away from tests on ridiculously small bits of paper, which may well be completely unrepresentative; he studied whole rolls rather than square centimetres. How otherwise can you spot a single shive or other potential fracture points as being likely to cause a break in several miles of paper? (For further comments and references, particularly to George Sears, see my paper 'Mechanical Pulp —the Neglected Gold Mine', *Tappi*, 1968, **51** (9), 39A.)

Dr L. S. Nordman Prof. Renata Marton did not mention the time lag between printing and splitting of the sheet of paper. It must have a profound influence on the appearance and situation of the maximum value, because we have found that there is a marked redistribution of the vehicle in the sheet when the time after printing increases.

Prof. Renata Marton We did not split right away after printing, because it is impossible to split 14 or 15 layers very fast, though we consider the time to be very important. We have not yet determined how long the vehicle continues to migrate, but we intend to do so. The time between printing and testing was about 15 min.

Dr J. Marton As Mr Underhay has already mentioned, the runnability of newsprint is more affected by mechanical condition of the roll and by the

Under the chairmanship of Dr J. A. Van den Akker moisture content than by some other fundamental paper properties like tear or smoothness. Nonetheless, printability problems are quite important for other categories of paper like fine papers coated or uncoated used for more quality printing. We should not therefore consider everything from the point of view of newsprint.

Dr J. Grant I am not quite clear how Prof. Marton's method, which intrigues me very much, differentiates between the progress of the pigment and the progress of the ink vehicle through the thickness of the paper. One illustration showed both as separate curves; but, if she activates the ink as a whole, how is one distinguished from the other?

I would like to add a few remarks of a general nature, which suggest themselves to me as a result of listening to the papers this week.

I am all with George Underhay in that we should try to keep our feet on the ground in the practical applications of the knowledge that we are hearing about, although this symposium is of course concerned with the fundamental properties of paper as distinct from their immediate practical use.

I have always regarded paper as having properties in equilibrium. Thus, when you attempt to improve one property, you invariably lose on another. The simplest example I suppose is the one I mentioned the other day—when one beats pulp to improve strength, one loses opacity, dimensional stability and one can give many other examples. So the problem really arises how can we take this welter of complicated factors that go to make up good printability or runnability and find optimum compromise among them all to give the best results on the papermachine.

My suggestion is of course not original—I know that it has been applied, especially in North America. I refer to furnish optimisation, which I believe is the real answer to the practical application of these recondite properties. I have carried out large-scale experiments on this and was very impressed by the results obtained by feeding into a computer the desirable characteristics from a number of different pulps—hardwood pulps, long-fibred pulps and others—and programming the computer to give the proportions that we should use and how we should treat the pulps in order to obtain the best combination of printing characteristics. I believe that this is really going to be the best way of achieving something practical out of the theory that we have heard during the course of this meeting.

Prof. Renata Marton I was rather expecting this question. We were unable to provide specific information about the distribution of the radioactive tracer between the carbon black and the ink. We are working on this now, but we assumed equal specific activities of the carbon black and the ink vehicle. We know, however, that errors are introduced by this assumption, but they should not affect the qualitative conclusion I have presented.

Dr J. Grant The difficulty is that the vehicle and the carbon black travel through the paper at different rates and to different extents. Unless you separate their effects, the results are really meaningless.

Prof. Renata Marton Observation under the microscope of each layer helped to establish where the carbon stopped and how the vehicle continued to migrate. I presented a few examples of what we are doing, but the work is not finished and we hope greatly to improve on this promising method.

Mr R. Rahkonen I would like to add one point that might be of interest. I think it might be possible separately to label the pigment and rhe vehicle with two labelling substances having different spectra of radioactive radiation. Then it should be possible using Prof. Marton's technique to measure separately the amounts of pigment and vehicle in the different layers of the paper simply by measuring the intensity of radiation at two different wavelengths. At Rauma, we have used the same technique to measure separately the flow of wood chips and of coating liquor in a continuous digestion system.

Mr J. R. Parker May I ask Prof. Marton how her work compares with that by Larsson, who has used similar techniques?

Prof. Renata Marton Yes, we know of Dr Larsson's work very well and we co-operate closely. He uses a Geiger-Müller counter, which is much less sensitive than a liquid scintillator counter, for this counts a hundred times less radioactivity than a Geiger-Müller counter. Our curves are similar to some extent, therefore, but we regard the scintillation method to permit much greater precision, since we can detect parts of milligrams of ink in each layer.

Dr A. B. Truman It is intriguing to think that one might be able to feed into a computer the basic physical data on paper properties to obtain from it the desirable printing characteristics of the sheet (which I would suspect are very difficult to define).

In my opinion, the problem is more educational than technological. The papermakers must be educated to make a consistent product with controlled properties and the printer must learn to use the paper in an intelligent way. I can cite an example of a troubleshooting job that I went on recently; a printer of newsprint had had considerable web breaks on his machine. On questioning him closely, I discovered that the firm had recently installed air conditioning equipment that considerably reduced the ambient moisture content. I explained to him the relationship between that and paper properties, the tensile strength and stretch—and really that in itself was the solution to the problem.

However erudite our study of the factors contributing to good printability and runnability, the effort will be to no avail if we do not communicate effectively with the papermaker and the printer.