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INFLUENCE OF FIBRE TYPES, SIZE AND SHAPE ON PAPER PROPERTIES FOR PULPS OTHER THAN WOODPULPS

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Synopsis

Paper formation phenomena are more closely related to fibre structure and fibre morphology in the case of non-wood fibres than with chemical woodpulp fibres. Nevertheless, the non-wood fibres commonly used for papermaking cannot be considered as a class on their own, but must be studied separately in these respects. This method is applied in particular to cotton, linen, cereal straws, esparto grass, bagasse and bamboo, with special reference to the dimensional structure of the fibres and their associated structures. Further research work on these fibres on the same lines and scale as that accorded to woodpulp fibres should give valuable information on the factors determining paper formation on the machine.

L'influence du type de fibres, de leur forme et de leurs dimensions sur les caractéristiques papetières des pâtes autres que les pates de bois

La structure de la fibre et sa morphologie exercent une influence particulièrement importante sur le processus de la formation de la feuille dans le cas des fibres autres que celles de pâtes de bois. Néanmoins, ces fibres, utilisées couramment pour la fabrication du papier ne peuvent être considerées comme formant une catégorie unique, mais doivent être étudiées séparément. Cette méthode s'applique particulièrement au coton, au lin, aux pailles, à l'alfa, à la bagasse et au bambou. Il faut insister sur la structure dimensionnelle des fibres et sur les propriétés de celles-ci qui en dépendent. D'autres *travaux de recherche sur les fibres dans le même sens et sur la même échelle que ceux consacrés aux fibres de bois devraient donner des informations utiles sur les facteurs déterminant la formation du papier sur machine.*

Der Einfluss von Art, Grösse und Form von nicht von Holz stammenden Fasern auf die Papiereigenschaften

Bei nicht von Holz stammenden Fasern sind die Vorgänge der Blattbildung wesentlich enger mit Struktur und Morphologie der Fasern verbunden als bei Holzzellstoffasern. Doch lassen sich diese nicht von Holz stammenden Fasern nicht gemeinsam betrachten, sondern müssen getrennt untersucht werden, was man für Baumwolle, Leinen, Getreidestroh, Esparto, Bagasse und Bambus besonders im Hinblick auf die Dimensionsstruktur der Fasern tat. Weitere Forschungsarbeiten an diesen Fasern, in gleichem Umfang wie sie für Holzzellstoffasern durchgeführt wurden, dürften wertvolle Informationen für diejenigen Faktoren liefern, die die Blattbildung auf der Papiermaschine bestimmen.

Introduction

A NOTEWORTHY feature of the symposium *Fundamental aspects of fibres and their treatment for papermaking* held in Cambridge in 1957 was that the papers under discussion were confined almost exclusively to wood and woodpulp fibres. This was understandable in view of the importance of such fibres for papermaking and the personal interests of most of the participants; it was anticipated that similar circumstances might well apply to this present symposium. Although woodpulp is used for papermaking on a world-wide scale and to a far greater extent than all the other papermaking fibres added together, there are certain national paper industries in which it plays a less predominating part and even a minor part. Moreover, on purely scientific grounds, any proper treatment of the subject here would be incomplete without reference to fibres other than of wood. The purpose of this paper, therefore, is to assess the effects on the formation and structure of paper of the size and shape of these 'non-wood fibres' in much the same way as has been done for woodpulp in the preceding paper by Dadswell and Watson.

In approaching this objective, one encounters immediately a difficulty because of the heterogeneous nature of fibres collected together under the heading 'other than of wood'. Indeed, there are few (if any) important chemical or morphological features that distinguish them as a class from wood fibres. In fact, the differences between the different non-wood fibres are sometimes much greater than the differences between certain of them and some woods; this applies especially when the hardwoods are considered. It is, therefore, necessary to consider each of the fibres separately, in so far as this is possible—and this means that a selection must be made.

Table 1 sets out the approximate average dimensions of a number of non-wood fibres in comparison with typical softwood and hardwood fibres. Also included are the ratios of length to diameter and the botanical origin. The fibres marked with an asterisk are those dealt with specifically in the present paper; they are the principal non-wood fibres used in the pulp and paper industry. It should be noted that the figures are given as an indication only. All the fibres show wide variations in dimensions, particularly in length.

TABLE 1

Fibre	*Length, mm*	*Breadth, mμ*	*Ratio, length/breadth*
Coniferous wood	4.0	40	100
Deciduous wood	2.0	22	90
*Cotton (seed)	45	20	2 300
*Cotton linters (seed)	10	20	500
*Linen (bast)	55	20	2 800
*Cereal straw (bast)	1.8	14	130
*Esparto (leaf)	1.5	10	150
*Bagasse (stem)	3.0	30	100
*Bamboo (stem)	1.8	15	120
Sisal (leaf)	2.8	21	130
Jute (bast)	2.5	18	140
Ramie (bast)	130	40	3 500
Manila hemp (leaf)	6	24	250

* Dealt with specifically in this paper

In what follows, the tabulated data for each fibre are amplified and each fibre is discussed in turn, principally with respect to its subsequent behaviour on the papermachine and its effects on the formation and structure of the paper. An important point to remember in this connection is that, whilst the tabulated data refer to unbeaten fibres, the properties of the fibres in the paper depend on their behaviour in the beaten state. This, of course, applies equally to wood fibres, but the effects of beating with wood are often less, especially, for example, in comparison with beaten linen or cotton fibres.

Cotton

THIS material needs to be considered under two main headings, namely, natural cotton and used cotton (that is, rags).

Natural cotton (Gossypium spp.)

This material usually comes to the papermaker as linters, the shorter hair fibres that cover the seed boll of the cotton plant. The longer lint fibres are too valuable for textile use to be used for paper manufacture. Apart from their dimensions, the linter fibres have, structurally, some points in common with the wood fibre. Thus, the cell wall is relatively thin (about 0.2 μ) and it consists of randomly oriented fibres with a lamellated secondary wall. An important characteristic that is peculiar to the cotton fibre is its twist, but this is readily eliminated by mild chemical processing.

Chemically, however, the differences between cotton and woodpulp fibres are more important: thus, a thin layer of pectins and wax surrounds the linter cell wall, which is removed fairly readily by a light alkaline cook, leaving a residue of almost pure cellulose, that is to say, virtually free from lignin; the cellulose of cotton linters differs from that of wood in that the crystallites or micelles that result from severe hydrolysis are approximately 33 per cent longer than those obtained from wood, although there is little difference in their width.[1] This corresponds with the known higher mean molecular weight of cellulose from cotton compared with cellulose from wood, approximately D.P. 8 000 and 2 000, respectively.

It is difficult to correlate these known differences between wood and linter fibres with their different effects on paper formation. Expressed in simple papermaking terms, the major difference is that the linter fibres are brittle and will not stand up to intensive beating. Under these circumstances, they behave rather like filler fibres such as the fibres of hardwood pulps, although they are too costly to be used for this purpose alone. Fig. 1 and 2 illustrate a typical effect of intensive beating. The other important characteristic of linter pulps is the softness and bulk of papers made from them. This is retained on beating to a greater extent than the fibrillation encountered with cotton rags and it shows itself in the properties of bulk and absorbency, for example, that are characteristic of blotting paper made from cotton linter pulp.

Within recent years, attempts have been made to modify the linter fibre chemically.[2] Low substitution hydroxyethylation in particular has been found to give papers having improved strength, more uniform formation and good permanence and surface characteristics. The surface characteristics of

Fig. 1

Fig. 2

a fibre of this kind are compared in Fig. 3 and 4.[2,3] Tables 2 and 3 show the effect of these fibres on increasing the strength properties of other furnishes. Table 4 demonstrates their effect on porosity.

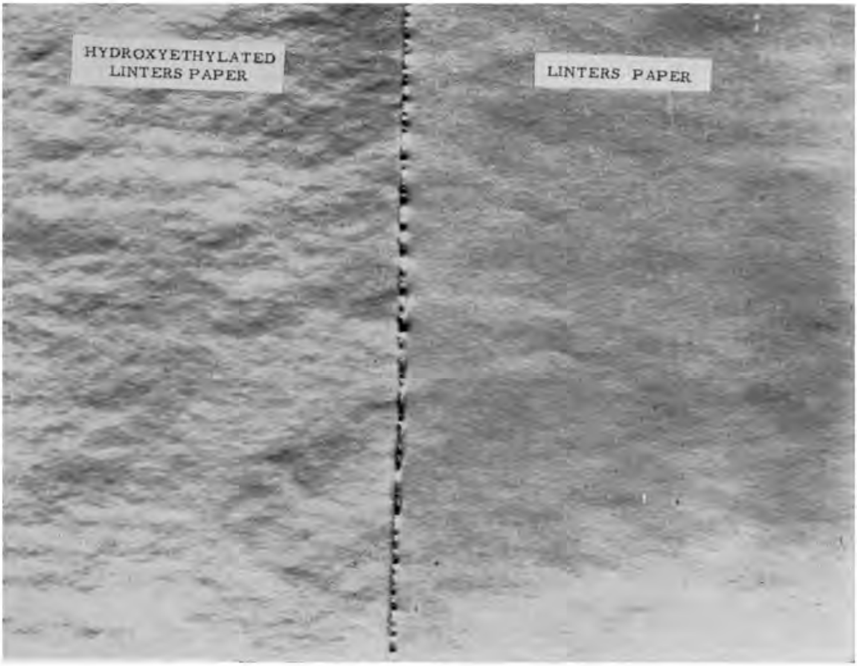


Fig. 3 ***Fig. 4***

TABLE 2—50 PER CENT COTTON-CONTENT BOND PAPER: MILL DATA

Fibre	*Control*	*New furnish*
Rag fibre, per cent	25	—
Regular cotton linters, per cent	25	—
Woodpulp, per cent	50	50
Hydroxyethylated cotton linters, per cent	—	50
Paper properties		
Basis weight, lb (17 × 22 in, 500 sheet ream)	20	21
Bursting strength, lb/in²	42	45
Tearing strength, g per sheet (machine-direction)	55	65
Folding endurance, double folds (cross-direction)	200	300
Opacity, per cent	83	81

TABLE 3—100 PER CENT COTTON-CONTENT LEDGER PAPER: MILL DATA

Fibre	*Control*	*New furnish*
Rag fibre, per cent	82	64
Regular cotton linters, per cent	18	—
Hydroxyethylated cotton linters, per cent	—	36
Paper properties		
Basis weight, lb (17 × 22 in, 500 sheet ream)	32	32
Bursting strength, lb/in²	80	77
Tearing strength, g per sheet (machine-direction)	160	145
Folding endurance, double folds (cross-direction)	600	690
Opacity, per cent	90	89

TABLE 4—FILTER PAPER: MILL DATA

Fibre	*Control*	*New furnish*
Regular cotton linters, per cent	80	40
Woodpulp, per cent	20	10
Hydroxyethylated cotton linters, per cent	—	50
Paper properties		
Basis weight, lb (25 × 38 in, 500 sheet ream)	208	206
Bursting strength, lb/in²	22	22
Water porosity, sec per 100 ml	58	35
Air porosity, ft³/min/ft²	7	12

These treated linter pulps also have a slightly lower alpha-cellulose content and caustic soda-soluble fraction than have ordinary linters: however, their crystallinity as determined by the X-ray diffraction method is greater. Fig. 5 is of special interest in that it shows the effect of beating the treated linters and should be compared with Fig. 2.

The difference in behaviour of the treated and untreated linters supports the view that the failure of linters to develop strength properties on beating is due to the stiffness of the fibrils and their inability to collapse. The partial hydroxyethylation modifies these properties whilst preserving the fibrillar structure.

Used cotton

This material comes to the papermaker in the form of rags, which vary very widely in quality according to age, cleanliness, the presence of other fibres and non-fibrous materials (such as fillers or dyestuffs), colour (that is to say, whether natural, bleached or dyed) and so on. This present paper can deal only with the 'purest' type of rag, which most closely approaches the cotton fibre in its virgin condition, that is to say, new unbleached white cuttings. This restricted consideration arises from the fact that this paper is concerned only with the effects on formation of the fibre as such; other constituents present may have profound modifying effects.

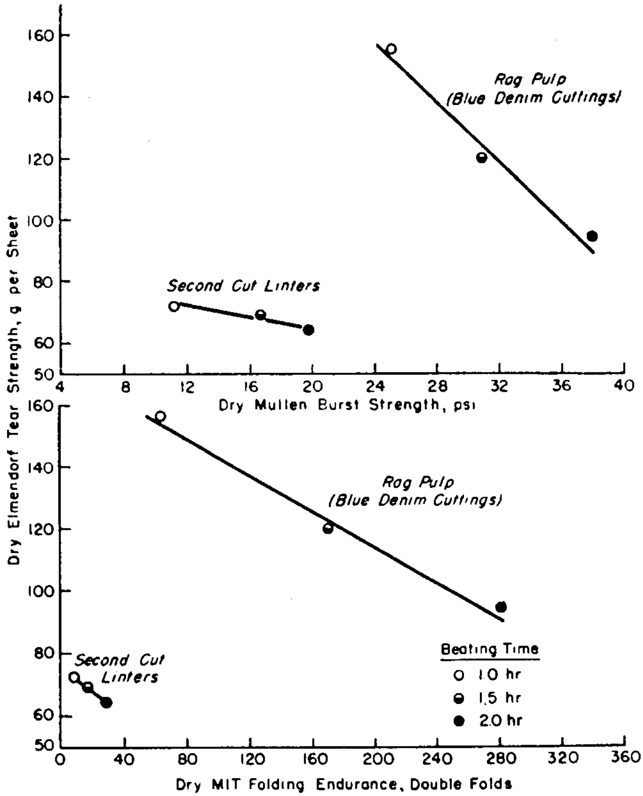
Fig. 5

As Table 1 shows, there is a striking difference in length between cotton linter fibres and natural cotton fibres as one would expect. There are, however, qualitative as well as quantitative differences and these profoundly affect the fundamental behaviour of the fibres on beating. This is demonstrated in Fig. 6 and 7.[2] The graphs in these figures are obtained by plotting two inversely related strength properties, for example, tear against folding strength and/or tear against Mullen bursting strength for various beating times.

The much higher strength of the cotton rag fibre as shown by these curves is only partly explained in terms of the greater length of this fibre.

Another, but perhaps less important, influence is the fact that the chemical processing necessary for the preparation of cotton linters is far more drastic than that used for cotton rag. Typical conditions are compared in Table 5.

It will be noted that good cotton rag can be used with little or no chemical treatment, assuming, of course, that it is not coloured and contains



Handsheet basis weight, 40 lb (24 by 36 in , 500 sheet ream)

Fig. 6 (*above*) and ***Fig. 7*** (*below*)

no fillers; it has a low bleach requirement. Actually, the chemical processing of linters is more drastic than the linter fibre itself really requires; the particles of linter shell that inevitably accompany the fibre are more difficult to resolve than are the fibres themselves and the associated dirt, etc.; but it is this shell that sets the standard for the chemical processing involved. The papermaker

TABLE 5

Cooking conditions	*Cotton fibres (rags)*	*Cotton linters*
Caustic soda, per cent on weight of material	2	8
Pressure, lb/in^2	40	50
Time on pressure, h	3	8

must have clean pulp, but, if the shell and other dirt could be removed mechanically, the above process of chemical treatment would be milder and the curves given above would undoubtedly come closer together, though they would still far from coincide. On the other hand, if cotton rag is beaten with sharp tackle set close together, an effect very similar to that of beating cotton linters results (Fig. 2).

In many types of paper for which the best grades of cotton rags are used, this advantage of strength, though important, loses some of its significance, because the papers concerned are heavily tub-sized with gelatine afterwards. Since linter fibres have a high degree of absorbency for gelatine in this process, the substitution of cotton rags by linters does not necessarily affect the strength of the finished papers very adversely; and the hall-mark of '100 per cent rag' is still satisfied.

From the point of view of formation, the essential difference between untreated linter and cotton rag pulp is that the former is in effect a filler-fibre giving close formation, softness and absorbency; on the other hand, cotton rag is a versatile fibre that can produce anything from a structure similar to that of linters to a wild sheet, according to the method of stock preparation used. For this reason, among others, stock preparation by refiners has not yet superseded controlled beating in this instance.

Linen or flax (*Linum spp.*)

THIS fibre is analogous with cotton in that it is usually ranked as a grade of so-called rags; however, it has no counterpart corresponding with linters. It also is an angiosperm (seed-bearing plant) and it is dicotyledonous, since the seeds yield pairs of leaves. In such plants, the vascular bundles of fibres are arranged in cylindrical form around the pith and are known as bast fibres.

As with cotton, flax is essentially a textile fibre and the papermaker receives it in the form of linen rags. Flax as such (as distinct from linen rags) can be used for papermaking, but only the waste flax tow is available at a price commensurate with that of paper production. This is because the chemical process is costly and the yield is low. Much the same applies to the straw from flax plants grown primarily for linseed oil production, the fibres of which are too short for the usual textile applications.

The great length of the linen fibre is apparent from Table 1. Unfortunately, our knowledge of the fibre structure is relatively scanty and contradictory. There is reason to believe that three layers are present.(4) The inside layer is relatively thick in relation to the others and has a twist in the reverse direction to the thinner inner and outer walls. The seat of the

Fig. 8

great strength of linen is in fact obscure, but it is associated with its low lignin content. This in turn is due to a great extent to the very selective biological (as distinct from chemical) method used to isolate the fibre from the plant, namely, retting. On the other hand, the mean molecular weight of linen cellulose is similar to that of cotton.

Undoubtedly, the important practical papermaking feature of linen fibres is the readiness with and the extent to which they fibrillate and this is made full use of, for example, in the manufacture of strong papers such as bank notes (Fig. 8). It should be noted that this property manifests itself at a very early stage in the beating operations. For the same reason, it is difficult to cut linen fibres without fibrillating them, a necessity that, in fact, seldom arises, because linen is used to obtain high strength and cheaper fibres are used to close up the sheet and assist formation. In this sense, therefore, linen fibres are far less versatile than those of cotton.

Other bast fibres

In the same general botanical classification as flax are jute, hemp, ramie and sunn hemp, all of which are used to some degree in speciality papers. They resemble linen in general properties, but, as Table 1 shows, they differ from it in degree. Ramie (China grass) is of special interest, since it was used originally for the manufacture of Bible papers, for which thinness and strength are all-important. Its remarkable length qualities are indicated by the data in Table 1.

Cereal straw

Pulps from such sources are fairly widely used nowadays in certain parts of the world. They comprise principally wheat, rye, oats, barley and even rice straws. In dimensions, the fibres of the cereal straws are comparable with those of the wood fibres rather than with those of rags; even so, the straw fibre is far shorter than that of wood (Table 1). The wide lumen is to be noted; it occupies 25–30 per cent of the width of the fibre. It is the associated structures and especially the pith cells, epidermal cells and hairs comprising the non-fibrous part of the pulp, however, that give the straw its characteristic properties and influence on formation. The pith cells in particular vary in shape from almost circular to fibre-shaped and they can have rounded ends. Their special characteristic is their thin walls, which appear nevertheless to be very strong, because the chemical treatment used to isolate the fibres from the straw removes the contents without destroying the walls. The walls then collapse, rather like empty sausage skins and blank off the pores of the papermachine wire, thus giving the impression of wetness in the sense used to describe intensive beating.

Quite apart from this purely physical effect, however, the straw does develop strength on beating owing to its hemicellulose content (35–50 per cent). This has been proved by beating experiments on pulps from which most of the associated structures have been removed by screen fractionation. It is also in line with the low tearing strength of straw papers even when the stock preparation is adjusted to maintain the maximum fibre length.

It is noteworthy that the chemical compositions of strawpulps show wide variations according to species, geographical origin, even from year to year.

In this respect, rice straw is outstanding, since its content of mineral matters varies in the range 5–20 per cent in different parts of the world. There is no evidence, however, that these variations markedly affect the structure of the fibre or its behaviour in the papermaking process.

Another special feature of strawpulp, which is important when considering the formation of paper made from it, is the marked way in which its properties may be varied by altering the methods of chemical processing used. Thus, straight caustic soda cooks give 'wet' pulps, which part unwillingly with their water, drain slowly even before beating and subsequently hydrate very readily. The neutral sulphite process and processes utilising a gentler alkaline cook and relying on chlorination and bleaching to complete the fibre purification process, give pulps that drain much more freely. In such cases, the sausage-shaped cells are not completely emptied of their contents and the skins do not prevent water drainage to the same extent as with the caustic soda pulps. Indeed, they serve more as filler-fibres and contribute as such towards greater opacity and dimensional stability.

These effects are demonstrated by the data in Tables 6 and 7. Other fibres are included for comparison and the relative transparency of straw fibres treated by any of the different processes mentioned is to be particularly noted.

TABLE 6[5]

Type of paper	*Relative opacity*	
	Unbeaten	*Beaten, 50° S.R.*
Esparto, soda	100	95
Birch, sulphate	85	84
Spruce, sulphite	84	78
Bagasse, soda	84	75
Wheat straw, chlorine soda	84	72
Wheat straw, mechano-chemical	85	70
Wheat straw, monosulphite	86	73
Wheat straw, soda	82	68

Rice straw presents a particular case, because it usually contains a relatively high content of silica, up to 20 per cent. It is not always convenient (or desirable) to eliminate this in the process of isolating the fibres and its presence contributes hardness and transparency. It does not, therefore, play the simple part of an ordinary mineral fibre such as asbestos or even of a loading.

TABLE 7

Type of paper	*Wet expansion, unbeaten*	*Wet expansion, 50° S.R.*
Straw, hot soda	4.2	5.3
Straw, monosulphite	3.8	5.0
Straw, soda chlorine	3.7	4.9
Coniferous wood, sulphite	3.8	4.8
Hardwood, sulphate	2.2	3.1
Groundwood	1.8	2.1
Esparto, hot soda	1.3	2.1
Esparto, continuous kraft	1.4	2.3
Esparto, Pandia	1.5	2.2

Esparto grass (Stipa tenacissima)

THIS fibre is of special importance, not only because of its wide use in British papermills, which for exactly one century have been importing it from North Africa and converting it into pulp and paper, but because it has unique properties of opacity, dimensional stability and bulk. These are demonstrated in Tables 6 and 7, which also show that these properties are virtually independent of the extraction process used.

Esparto grass is a monocotyledonous leaf fibre, with a relatively high ratio of length to diameter (Table 1). Unlike the commoner papermaking grasses, such as cereal straw, the fibres come from the leaf and not from the stem. In hot weather, the leaves of the grass roll up into tubes and these are hand-harvested by pulling clumps of them out of their surrounding sheaths. By reason of their leafy structure, therefore, esparto grass fibres are free from nodes and, indeed, are relatively easy to convert into cellulose pulp by chemical methods.

The fibre structure of esparto grass is all-important to any consideration of the properties of papers made from it. The fibres—though slim, sinuous and usually pointed (Fig. 9)—have relatively thick walls. Because of this, they retain their approximately circular cross-section when they dry and, by reason of this, they have a certain amount of retained internal flexibility. This effect of drying is much less apparent with other fibres, notably wood fibres that, when they dry out, form flat ribbon-shaped structures. This characteristic doubtless accounts for many of the properties that are peculiar to esparto papers. It may account also for the fact that esparto resists the beating process in the sense that it shows no sign of fibrillation, loss of bulk or undue wetness, despite the fact that it has a hemicellulose content of approximately 30 per cent consisting mostly of xylans.

The low wet expansion of esparto pulp may be related also to the fibre structure. Thus, the flat, ribbon-like fibres of a dense sheet such as that of straw or of wood will swell on the addition of water and a wet-expansion effect will result. On the other hand, esparto fibres remain springy and so do not lie so closely together. Any swelling of individual fibres will be less than with wood, because the circular cross-section has not collapsed. Such water absorption as does occur will be taken up by the spaces between the fibres and so will not result in an extensive expansion of the paper sheet as a whole.

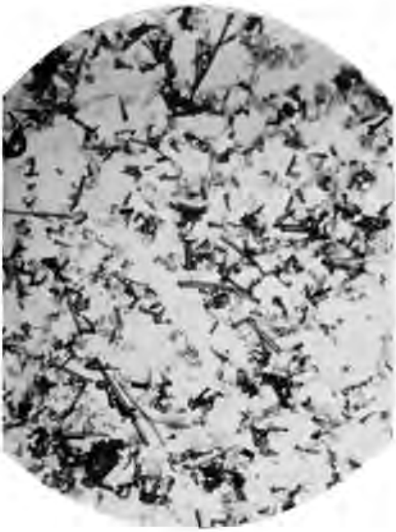


Fig. 9

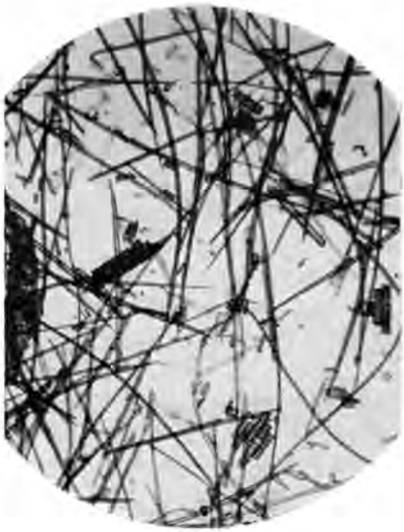


Fig. 10

The other very significant feature of the structure of esparto grass is the presence of seed hairs (trichomes) and other auxiliary structures associated with grasses (Fig. 9). The former are important, not only as a means of identifying the fibres microscopically, but as they also contribute materially to the closeness of formation, to the opacity and to the retention of these properties on beating. For some reason not fully understood, but believed to be due to their comma-shaped structure, the trichomes tend to be drawn to the underside of the sheet while it is being formed on the papermachine wire without, however, being all actually removed. The result is that, under certain conditions, it is possible to detect the thin ends of the hairs protruding on this side of the paper, while the hooked thicker ends are held by the fibres constituting the web of the paper. The operation of the printing machine (especially with offset litho printing) tends to pull these fibres out and this gives rise to fluffing trouble. This becomes acute when the fluff works back into the ink duct of the printing machine. As might be expected, this effect is particularly marked with papers having a high esparto content.

The trouble is obviated by prolonged washing of the pulp during manufacture to remove the small structures, but this results in a loss of yield, also of other fibre fractions that are responsible for closeness and opacity. Incidentally, such washing cannot be carried out by a filtration principle (for example, on a rotary vacuum filter), because the fines are drawn down into the mat of longer fibres and not through the wire. Consequently, the fines are retained in the mat. A washing drum method, in which the fines are kept in suspension in water on each side of the drum and flow through it only by virtue of the difference in levels on the two sides of the wire, is the simplest satisfactory method. Another method that has been used experimentally is the type of screen designed for removing the resinous fines from woodpulp. Fig. 9 shows esparto pulp before removal of such fines; Fig. 10 shows the fines so removed. These comprised 1.7 per cent of the dry pulp substance.

The small diameter of the esparto fibre means also that there are more fibre-to-fibre contacts in a unit volume than is the case with the woodpulp fibre. Even so, the proportion of bonded areas is relatively small and this too allows the esparto fibres to retain their flexibility: we thus have a relatively large number of small-area bonds compared with a smaller number of large-area bonds in the case of long-fibred woodpulps.

Bagasse (Saccharum officinarum)

THIS is the fibrous residue remaining after extraction of the sugar from sugar cane (*saccharum officinarum*). Consequently, it varies very widely in character according to the region, the extraction process used, the age of the plant, etc. There are, of course, fewer variations in the character of the pulp produced from different bagasses, but one very important variable is the amount of pith parenchyma associated with the fibrovascular bundles that comprise the pulp. The amount of pith in the original bagasse varies in the range 20–33 per cent according to origin and the amounts found in the pulp depend upon the degree of depithing applied in the pulping process. As one of several methods of depithing may be used, the variations are correspondingly great—for example, 5–15 per cent of pith in the final pulp.

The importance of the pith content arises from its dimensions (less than

0.4 μ) and from its pentosan content. The latter contributes materially to the high pentosan content of the bagasse pulp, on an average, approximately 30 per cent. Conversely, the lignin content is low, at approximately 19 per cent. The object of removing pith is to economise in the use of pulping chemicals and to raise the strength (both bursting strength and tearing resistance) and to reduce the ash content. It is therefore removed before pulping. Since there is a point at which pith removal becomes uneconomic in relationship to the operating cost, complete removal of the pith is not sought. Hence, the variable pith contents of the bagasse pulps.

Bagasse fibres considered on their own have a length-to-width ratio similar to, but rather greater than that of the conifers; in some respects, they behave similarly, although (being shorter) they give a much poorer tearing resistance. The pentosan content is responsible for much of the wetting that occurs on beating and, although fibrillation takes place, there is a marked reduction in bulk. Bagasse pulps are therefore very suitable for the manufacture of glassine paper and corrugating medium. Little is known of the actual structure of bagasse fibres and, apart from the modifying effect of the pith content indicated above, they may be regarded as very similar in behaviour to those of strawpulp (Tables 6 and 7).

Bamboo (Bambusaceae,* family *Gramineae)

THERE are over 1 250 species of bamboo, the principal families being *Melocanna*, *Ochlandra* and *Dendrocalamus*. They are indigenous to many parts of Asia and are widespread in occurrence on that continent and elsewhere in the world. It will therefore be appreciated that the resulting raw material as used for pulping will also vary widely, although here again there is less variation between the pulps made from different bamboos by the same pulping process.

Bamboos of different origins have in common the pronounced node formations in the stem and an absence of horizontal ray parenchyma, both of which affect the characteristics and properties of the ultimate pulp fibres. This is because both necessitate relatively drastic pulping conditions to produce a good bleachable pulp. The nodes are hard and resistant to penetration by cooking liquors and, although they are usually crushed before treatment, this process is not entirely effective. The absence of horizontal rays means also that liquor penetration is relatively difficult. As a result, normal bamboo pulps tend to be overcooked by woodpulp standards. It so happens that the fibrovascular bundles of bamboo have a concentrically layered structure, which gives them a certain amount of inherent stiffness and this is to a great extent retained despite the drastic cooking methods; in this sense, unbeaten bamboo fibres resemble those of esparto. However, bamboo fibres behave very differently to esparto on beating; they fibrillate and develop strength to a much greater extent. For this reason, bamboo is a more versatile fibre than esparto and can be used in a wide range of writings, printings and even wrappings. The fibrillation that takes place on beating

Fig. 11

renders the behaviour of bamboo to a great extent independent of the associated structures that remain in the pulp (Fig. 11).

These are chiefly the parenchyma (dimensions, $80\,\mu \times 18\,\mu$) and the epidermal cells characterised by their serrated edges. Here again, the pulping process reduces the proportion of fines; their inclusion can lower the tensile strength and tearing resistance by up to 30 per cent.[(7)]

Conclusion

It will be seen that a knowledge of the effects of the fibre structures of non-wood fibres on formation on the papermachine is based largely on observations of the microscopical structure. However, this simplified method of approach brings to light some interesting aspects of the subject of a general nature. It is interesting to speculate on the advances in our knowledge of paper structure and formation that might have been made had the non-wood fibres received the same intensive study that has been accorded to wood fibres.

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7. Bhargava, M. P., *FAO Conference on Pulp and Paper Development in Asia and the Far East*, Tokyo, 1960: Paper, V, b. 6

DISCUSSION

MR. A. P. TAYLOR: Referring to the graphs comparing the properties of linters with those as of rags, the importance of the effects that the previous history of the rags have on their properties should be stressed.

MR. H. W. EMERTON: Grant has referred to my statement that wood fibres can twist. This is quite distinct from the twisting in cotton, which is due to a shrinkage reflecting a change in the microfibrillar direction. In wood, the twist takes place, not within one part of the cell wall, but throughout the whole fibre about its axis.

DR. J. A. GASCOIGNE: In the preparation of cotton rags and linters for papermaking, it is rather surprising that the expensive caustic boiling at high pressures is still found necessary. In the textile industry, mixtures of anionic and non-ionic detergents with caustic soda and pyrophosphate are often used at atmospheric pressure. The bleaching of cotton seed hulls with peroxide and per-acids deserves further consideration. For example, dilute permonosulphuric acid brings about considerable embrittlement of seeds. The use of caustic soda solution with ammonium persulphate at the boil may also help. Does Dr. Grant know of the application of such methods to rag or linter preparation?

DR. J. GRANT: Some of these methods have been tried experimentally, but (so far as I am aware) they are not used on the commercial scale.

MR. H. G. HIGGINS: Watson has asked me to raise a point on his behalf. He writes, "At the beginning of his paper, Grant refers to the fibres of hardwood pulps as 'filler' fibres. He might be using the term to mean that such fibres give a more compact and denser sheet, but it can also be taken as meaning that they supply bulk and little else to the paper sheet. I think we should make it clear that hardwood fibres, properly used, are papermaking fibres in their own right."

DR. GRANT: I agree that hardwood fibres, if properly used, are papermaking fibres in their own right; my paper was not intended to imply otherwise. Most hardwood fibres are used as filler fibres—that is, to produce closeness of formation, bulk, opacity and flatness, as distinct from strength.

MR. T. A. FEAZEL: I would like to bring Dr. Grant's attention to the fibre length of cotton linters, which he has given as 10 mm. I think he will find that this value is usually about 2 mm. The longest fibres in cotton linters may be 10 mm, but not the average.

DR. GRANT: I would not regard 10 mm as unduly high for a good grade cotton linter as used in this country. I would regard 2 mm as definitely low.

PROF. B. STEENBERG: In several papers this morning, it has been stated that pulp fibres are circular in cross-section. Softwood pulp fibres, however, have approximately rectangular form in cross-section whether they are delignified or not. Dried softwood fibres have a more irregular outline, but the corners are easily discernible both in collapsed and uncollapsed fibres. Hardwood pulp is made up of a mixture of fibres with rectangular and circular cross-sections.

MR. D. H. PAGE: Dr. Grant mentioned that we might consider the peculiar properties of esparto in the light of our theory. As you have probably gathered, we did not really have time to deliver our theory properly, let alone touch on its applications. We have considered the effects of the common papermaking variables such as furnish, wet pressing, drying tension, fibre orientation in the light of our theory and we will be able to give a much more lengthy publication on this. As for esparto, all we can say briefly here is that we consider that the axial resistance of fibres to compression is vitally important in determining dimensional stability and this, together with the small amount of bonding, is probably the controlling factor.

THE CHAIRMAN: Are you prepared to concede the point that Jayme showed only the surface compacting rather than the whole fibre?

MR. PAGE: I think there has been some misunderstanding here: Jayme's micrograph supports our view. He has been able to show that the transverse shrinkage of the middle secondary wall of a fibre gives rise to enforced wrinkling of its own outer secondary wall. We suggest that it can furthermore give rise to enforced shortening of a fibre bonded to it.

MR. A. P. TAYLOR: Has Mr. Page examined esparto, which (having thick-walled rigid fibres) should show no microcompressions as in the case of thinner-walled wood fibres?

MR. PAGE: No, not yet, but we know the answer to that experiment before we do it! Seriously, this would be a negative experiment, but we will get round to it when we have time.

MR. N. SHOUMATOFF: Does the bond strength control this wrinkling or is it the compressive resistance of the fibre?

MR. PAGE: It is not fair to take up time on this here, but there are four factors—shrinkage, bond strength, axial resistance and fibrillation. All of these are important.

DR. G. N. RICHARDS: Leafy materials often contain large amounts of spiral thickened elements, which appear as helixes in the derived pulps. What is the utility of such elements in pulps?

DR. GRANT: These structures have no real papermaking value, though they may contribute slightly to the closeness of the final sheet.

MR. J. D. PEEL: Reliable data on the effect of silica on rice straw pulping and paper characteristics are not easy to find. Would Dr. Grant please enlarge his statement that silica in strawpaper increases its transparency, an effect one would not expect?

DR. GRANT: This matter has been studied by workers in Hungary. A paper containing silica (say, from rice straw) is more transparent than the same paper containing the same amount of conventional loading.

MR. W. H. HALE: I am under the impression that the papermaker obtains cotton fibre from two sources—(*1*) in the form of rejects from textile factories and as worn and discarded textiles and (*2*) as raw cotton. Does the term *second cut linters* refer to a particular grade from either or both these sources?

DR. GRANT: The term refers to a grade of raw cotton (see p. 576 under *Natural cotton*).

Written contributions

MR. F. J. T. HARRIS and MR. J. H. LARKING: Clarification of a number of points in the light of experience gained from the use of cotton in the form of both rags and linters might avoid possible misinterpretation.

Firstly, in Table 1, the figures quoted for the fibre length of cotton would appear to be much above average. More normal figures are 20–30 mm and 2–5 mm, respectively, for cotton staple and cotton linters.

Secondly, regarding the morphology of these fibres, cotton staple is generally recognised by a greater degree of twist than are cotton linters, the latter having no more twist than most woodpulps. In addition, the fibre cross-section of the two types is as shown in Fig. D15, the cell wall of linters, contrary to as stated, having a thicker cell wall than a wood fibre and an extremely narrow lumen.

With chemical treatment, commercially available linters are not degraded during manufacture to an extent that affects their subsequent strength characteristics to any degree; whilst cotton linters are generally regarded as giving high absorbency, they can be beaten by appropriate means to give

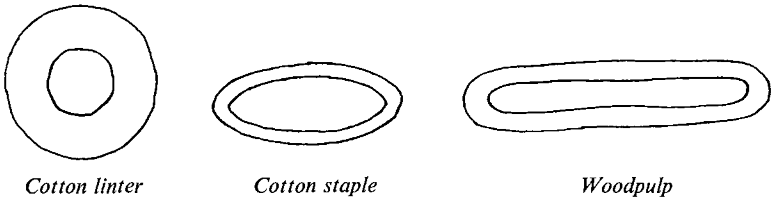

Fig. D15

papers of considerable strength and density. From this point of view, cotton linters cannot be fairly termed brittle and can hardly be regarded as a filler fibre. Indeed, even in their chemically unmodified form, cotton linters are taking the place of 'rag' fibres to an increasing extent, now that it is realised that they demand new concepts of beating, distinct from that given to 'rag' fibres.

DR. J. GRANT: The papermaking properties of the cotton linter fibres depend very much on the grade of linter used, quite apart from the pulping and beating procedures. Brittleness and filler fibre properties are more characteristic of the shorter grades of linters. I have dealt with fibre length in my reply to Mr. Feazel. I agree with the writers on the twist of these fibres, although this depends on the processing. They supply no evidence on the thickness of cell wall that leads me to depart from the statement made in my paper.