Effect of Beating on the Morphology of Bamboo Fibres and its Influence of Pulp Sheet Properties

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SUMMARY

Studies on changes in fibre morphology on beating in the soda pulps of three species of bamboos viz. *Dendrocalamus hamiltonii D. strictus* and *Melocanna baccifera* have shown that unlike wood fibres, bamboo fibres do not collapse on beating. Besides fibrillation, the fibres become more pliable as a result of progressive loss of outer lamellae of the cell walls. In some fibres, the lamellae instead of separating completely adhere to the fibres leaving large gaps between the partially separated layers which prevent fibre to fibre contact. The manner of separation of the layers evidently depends on the number, thickness and fibrillar orientation of the lamellae originally present int the fibres. The variations in the strength properties of the pulp sheets of the three species appear to be due to such differences in the cell wall architecture of their fibres.

INTRODUCTION

Investigations on the relationship between fibre morphology and pulp sheet properties have shown that bamboos constitute a group quite distinct from both soft and hardwoods. Unlike woods the fibre dimensions or their derived values are not useful in the classification of bamboos from the point of view of paper making (Monsalud 1965). Earlier studies on unbeaten and beaten pulp of 12 species of bamboos (Singh *et al* 1976 b) had indicated that the changes in fibre morphology on beating play a very important role in the development of strength properties in pulp sheets. Krishnagopalan et al (1975) are of the view that fibrillation is more important than fibre flexibility in the development of sheet properties in bamboo pulps. Studies on bleached pulp of *Dendrocalamus* strictus had shown that opening up of the cell walls on beating also effect strength properties of hand sheets (Singh *et al* 1976 a). For a better understanding of the mechanism of development of strength on beating a detailed study of soda pulps of three species of bamboos exhibiting wide differences in strength properties was undertaken and the results are presented here.

MATERIAL AND METHODS

Soda pulps from mature culms of three species of bamboos viz. *Dendrocalamus hamiltonii* Munro, *Dendrocalamus strictus* (Roxb) Nees. and *Melocanna baccifera* Kurz grown in the campus of this Institute were taken up for this study. All pulps were cooked under identical conditions and had a Kappa number of 26±2. These pulps were beaten in a valley beater at 35°C keeping the consistency at 1.57 per cent.

Fibre characteristics i.e. diameter, wall thickness, lumen width and fibre length were determined from a suspension of each pulp in distilled water. The average values of the fibre dimensions are based on a measurement of 300 fibres under a microscope. For fibre length, the averages are based on measurements of all fibres and fibre fragments over 100μ in length in each slide. To study the effect of beating on morphology in hand sheets made from the pulps beaten to different degrees of freeness. The sheets were embeded in a moisture of Dobeckot 505°C and the Hardener 750 (Singh *et al* 1976 a). About 5–8μ thick sections prepared on a sliding microtome and were stained in Iron alum and Haematoxylin and mounted in the same resin. The average width of the pulp sheets and percentage of void space were determined from five different portions of each section. The photomicrographs were taken with Zeiss camera microscope. For studying the sub-microscopic features of the fibres the hand sheets were examined under a Cambridge S4–10 scanning electron microscope after coating them with silver.

RESULTS

DEVELOPMENT OF STRENGTH PROPERTIES OF PULP ON BEATING

The variation in the sheet properties of the pulps

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TABLE-1

CHANGES IN FIBRE DIMENSIONS ON BEATING

Species	Freeness ml (C.S.F.)	Fibre dimensions			
		Length (μ)	diameter (μ)	Lumen width (μ)	Wall thickness μ
Dendrocalamus hamiltonii	550	2512	16.32	4.08	6.11
	400	2509	15.54	3.93	5.80
	250	2400	13.78	3.86	4.96
	100	2402	14.36	3.36	5.49
Dendrocalamus Strictus.	550	2581	16.36	4.50	5.92
	400	2363	16.18	4.98	5.60
	250	2450	14.12	3.48	5.32
	100	2332	15.21	4.69	5.26
Melocanna baccifera	550	2362	16.25	4.95	5.64
	400	2656	16.47	4.93	5.80
	250	2780	15.31	3.89	5.71
	100	2344	16.21	4.92	5.64

beaten to different degrees of freenesses are shown graphically in Figs. 1–3. From the point of view of strength properties the three species differ considerably, *D. hamiltonii* gives the highest strength while *M. baccifera* the values of the strength properties are lowest, and *D. strictus* is intermediate between the two. On beating the trend for the strength properties viz. breaking length and burst factor to increase is similar in all the three species and the differences among the three are maintained almost at the same level from 550 to 100 ml. C.S.F. With regard to tear factor however, there is considerable differences among the

EFFECT OF BEATING ON BREAKING LENGTH

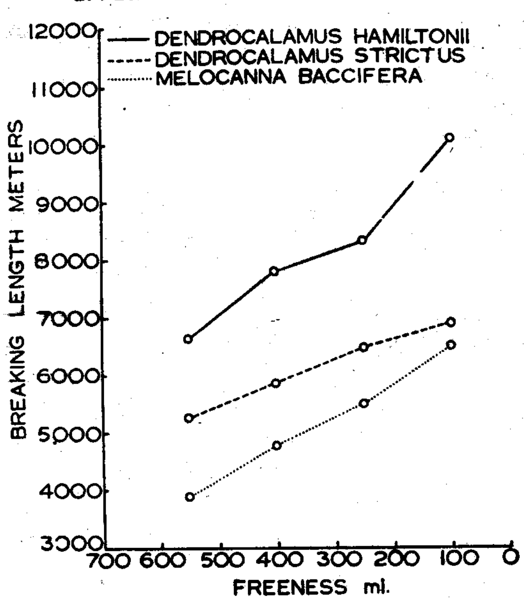


Fig. 1

EFFECT OF BEATING ON BURST FACTOR

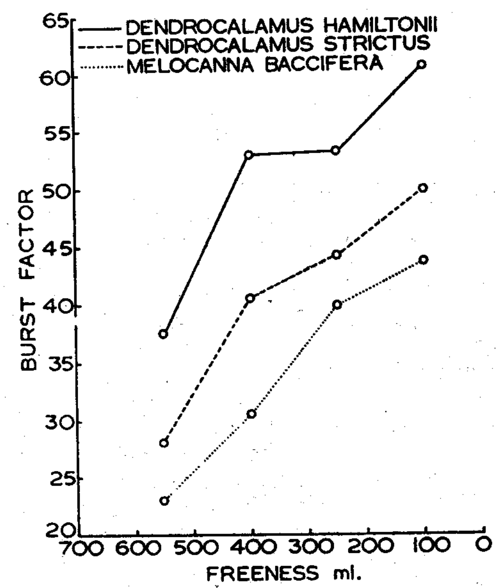


Fig. 2

three species. While in *D. hamiltonii*, there is a decreasing trend with beating, in *M. baccifera* the trend is opposite and while in *D. strictus* the tearing strength exhibits a decreasing trend after an initial rise (Fig. 3).

CHANGE IN FIBRE MORPHOLOGY ON BEATING

The average fibre dimensions of the different pulps investigated are given in Table-I. It will be seen from this table that the fibre length does not change

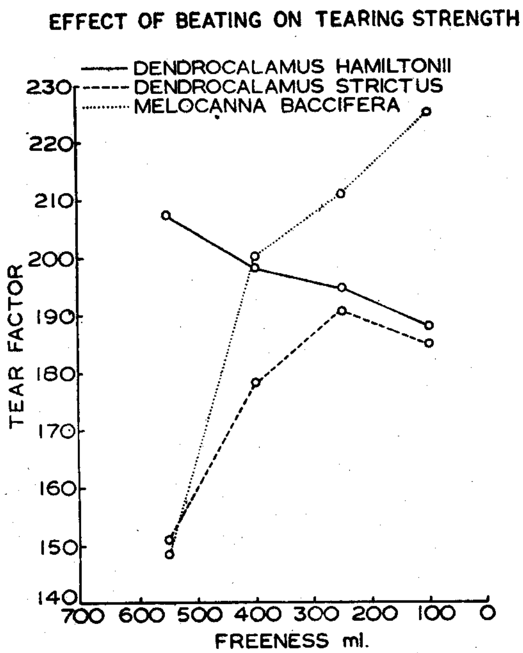


Fig. 3

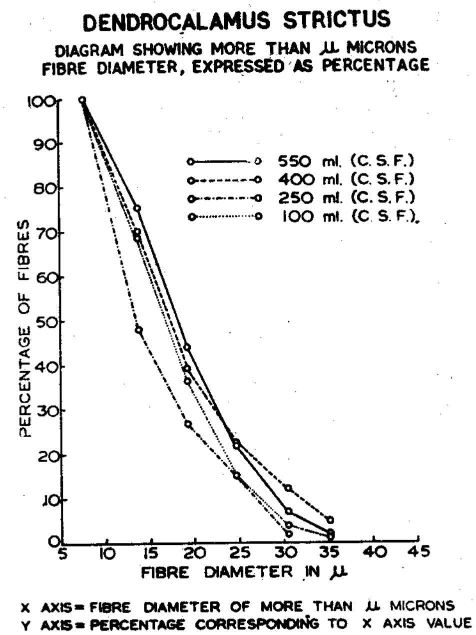


Fig. 5

to any great extent due to beating in any of the three species. The Somewhat irregular trend in the variations (Max. 8%) may be due to differences in the properties of fragments less than 100μ in length, in the different samples which were not taken into consideration in the measurements. Examinations of the slides under microscope also confirms it. In the pulps of *M. baccifera* the properties of debris less than 100μ in length appears to be somewhat higher than other two species.

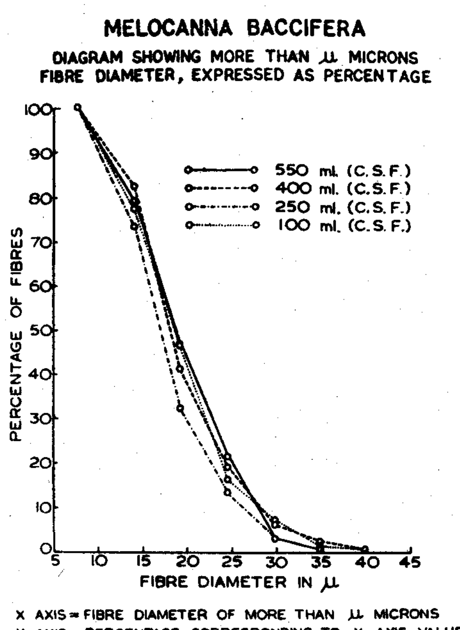


Fig. 6

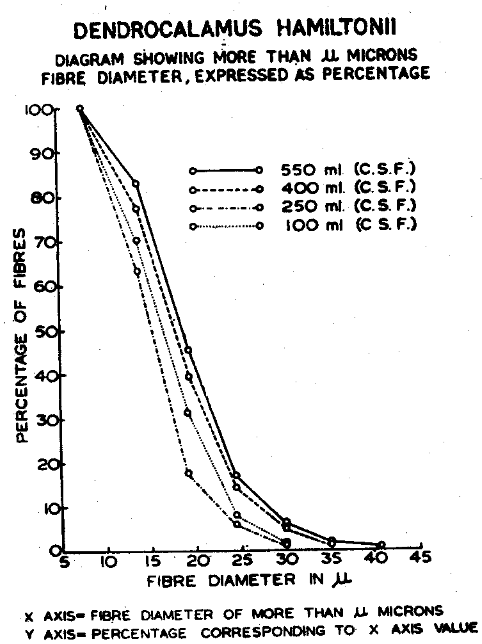


Fig. 4

In all the three species the average fibre diameter shows a decreasing trend on beating from 550 C.S.F. to 250 C.S.F. but show again an increase at 100 C.S.F. This trend is most distinct in *D. hamiltonii* than in the other two species. The cummulative frequency curve of fibre diameter at different freenesses also clearly bring out this fact (Figs. 4–6). The fibre wall thickness also follows the same trend in all the three species. However, a comparison of the three species indicate that the degree of change is maximum in *D. hamiltonii* and minimum in *Melocanna baccifera,* while *D. strictus* remains intermediate between the two (Figs. 7–9). With regards to lumen width the changes are not similar in the three species, while in *D. hamiltonii* it trends to decrease on beating in both *D. strictus* and *M. baccifera.* The average lumen width exhibits a decrease upto 250 C.S.F. and again an increase at 100 C.S.F. Somewhat similar to variations in fibre diameter. The cummulative frequency curve of the lumen width of the three species also indicates similar difference between them (Figs. 10–12).

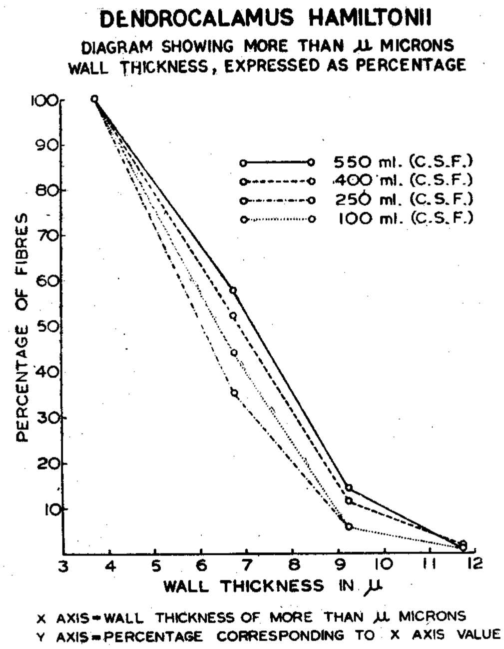


Fig. 7

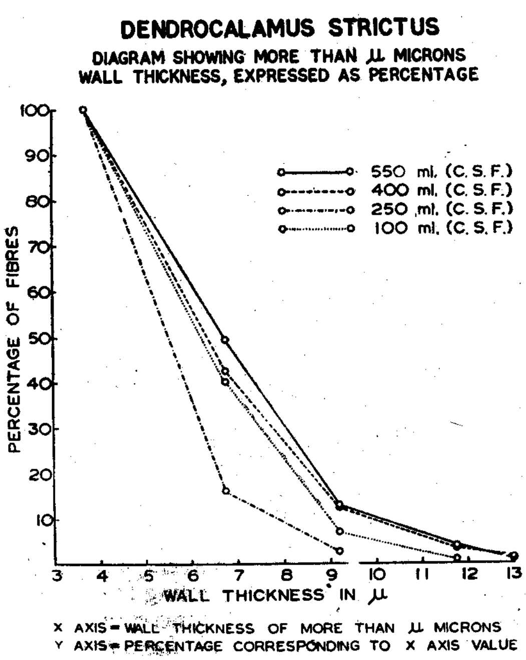


Fig. 8

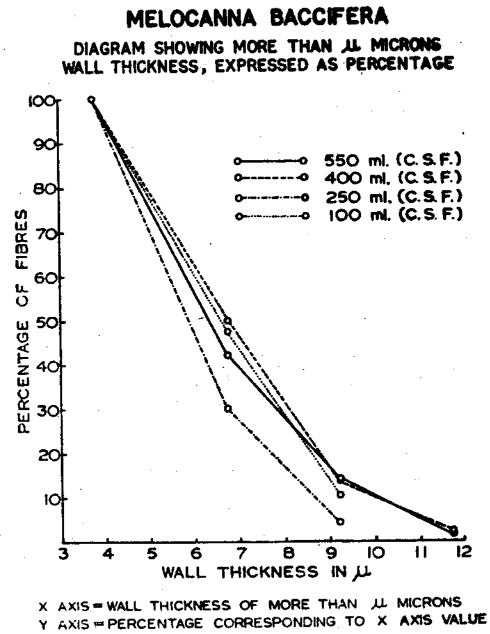


Fig. 9

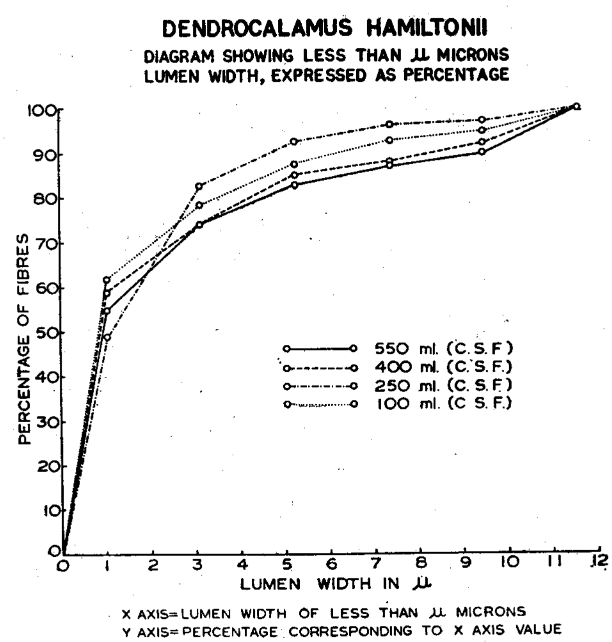


Fig. 10

TABLE–II

EFFECT OF BEATING IN THE COMPACTNESS OF THE FIBRES IN HAND SHEETS

Name of species	Freeness ml (C.S.F.)	Average width of the hand sheet, Microns	Average covered area, %	Average void area, %
Dendrocalamus hamiltonii	550	190.75	61.38	38.62
	400	175.00	59.67	40.33
	250	177.80	61.50	38.49
	100	143.50	66.34	33.64
Dendrocalamus strictus	550	178.50	68.67	31.33
	400	135.45	68.18	31.82
	250	171.50	74.32	25.66
	100	108.85	77.13	22.87
Melocanna baccifera	550	188.65	53.09	46.91
	400	169.05	71.90	28.09
	250	203.00	75.21	24.79
	100	112.35	78.58	21.42

The average void space determined from cross sections of the hand sheets are given in Table-II. It will be evident from this table that all the three species the fibres tend to come closer on beating.

A careful examination of the cross sections of the sheets shows that beating results in separation of the outer layers or lamellae which results in reduction in the cell wall thickness; this is particularly evident in *M. baccifera* where the separated lamellae very often forms an outer sheath round the fibres.

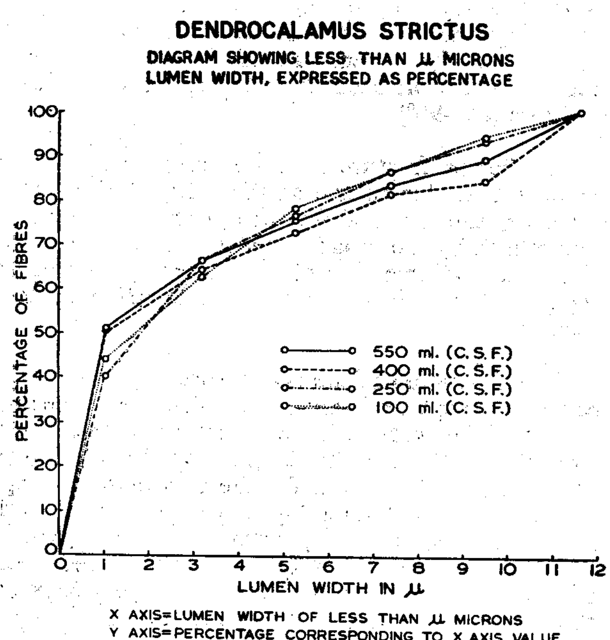


Fig. 11

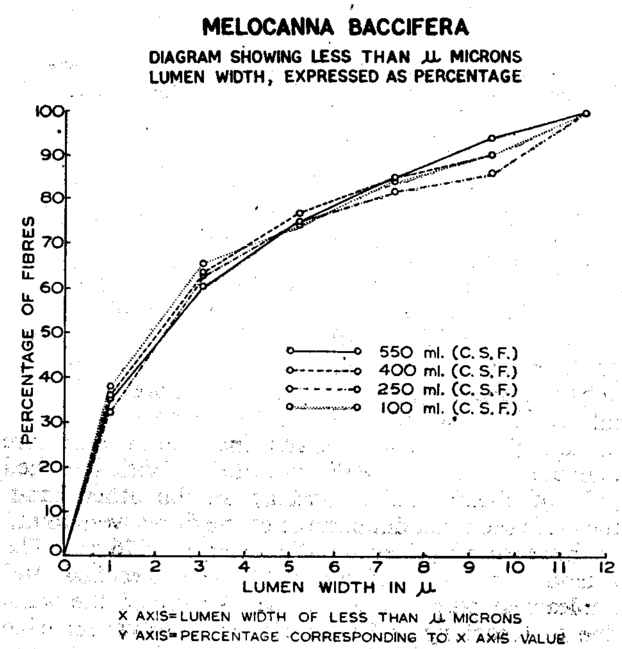


Fig. 12

Such ramnents of the separated lamellae are comparatively less common in *D. strictus* and very uncommon in *D. hamiltonii.* In the last named species the cell wall appears to form a solid mass with greatly reduced lumen.

Examination of the hand sheets under the Electron microscope shows that in all the three species there is considerable amount of fibrillation (Pl. II Figs. 1-3, a,b,c & d) as well as development of fissures in the cell walls which evidently reduces the stiffness of the fibres and helps in better fibre to fibre bonding.

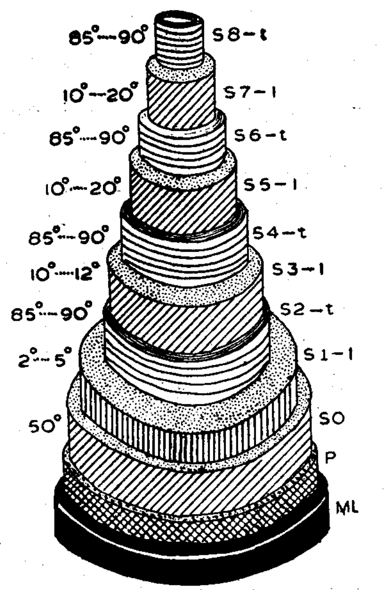


Fig. 13

Model of the polylamellate structure of a thick-walled bamboo fibre. (after Parameswaran and Liese 1976).

DISCUSSION

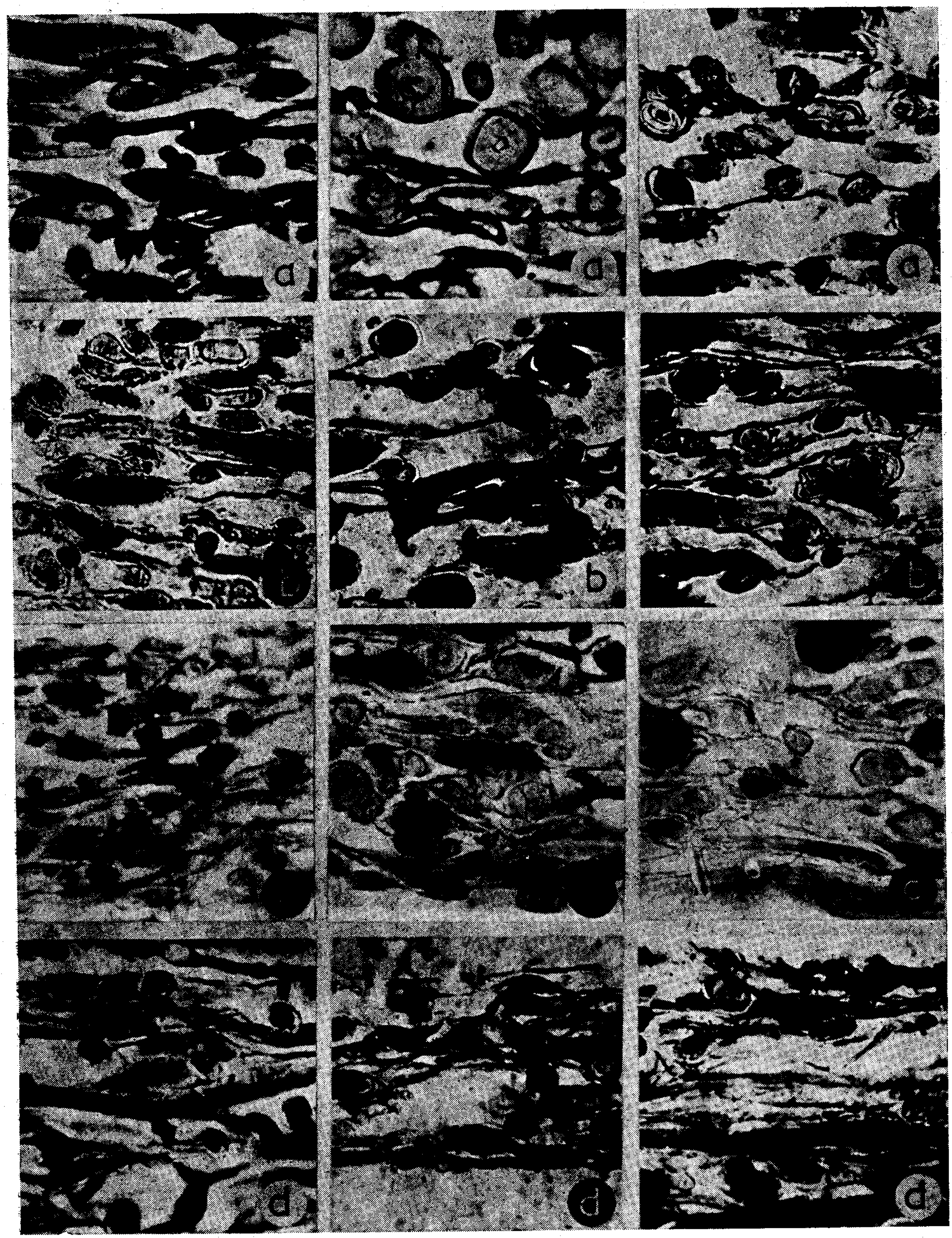
The most striking change observed in the fibres in all the three species of bamboos is the reduction in both fibre diameter and cell wall thickness on beating (except when the pulp is beated to 100 ml. C.S.F.). This is evidently due to loss of outer shells or lamellae of the fibres which disintegrate into debris a feature peculiar to bamboo fibres. At 100 ml. C.S.F. however, the walls appear to be broken up into shreds which results increase in both fibre diameter and cell wall thickness. With bleached pulp of *Dendrocalamus strictus* on the other hand, the cross sectional dimensions of the fibres were found to increase with beating (Singh *et al* 1976 a). The reason for such difference between bleached and unbleached pulp appears to be swelling of the walls due to bleaching and failure of the various lamellae to separate out on beating. Lack of any definite trend in fibre length on beating observed in this pulps is contrary to what has been reported for bleached *D. strictus* pulps where the fibre exhibited a trend for reduction on beating. This may be due to higher proportion of broken fibres in the bleached pulp. The tendency of the fibres to come closer with beating is similar to that observed in bleached pulp and is apparently due to the mechanism of surface tension (Emerton *et al* 1962). The higher proportion of void area in the bleached pulp sheet as compared with the unbleached ones appears to be due to comparatively larger gaps between the opened up lamellae of the fibre walls in the bleached pulp. The increase in the strength properties of the pulp sheats on beating is similar to bleached pulp but the values, as expected, are much higher.

The present study also confirmed the view of Krishnagopalan *et. al* (1975) that unlike wood fibres there is little or no collapse on beating and fibrillation plays a very important role in strength development. However, they have not noted the increase in the pliability of the fibres due to the loss of outer lamellae which also helps in the strength development. The percentage of fibres with obliterated lumen may also be a factor for the development of strength. It is probably not without significance that in *D. hamiltonii* which gives the highest strength, the percentage of fibres with obliterated lumen is also highest, while in *M. baccifera* it is the lowest and *D. strictus* occupies an intermediate position in this respect.

Unlike the three layered secondary walls of most wood fibres (which are usually designated as S1, S2 & S3) the thick walled bamboo fibres are polylamellated consisting of alternating broad and narrow lemellae or layers having different fibrillar orientation. The number of such layers varies with species Parameswaran and Liese (1976) report the presence of upto 18 such layers, in thick walled bamboo fibres. Tono & Ono (1962) report 7 to 9 such layers in *phyllostaches reticulata.* To distinguish these lamellae from those occurring in the woods Parameswaran and Liese have designated them as S1-1, S2-t, S3-1, St-4 S5-1 and S6-t etc. The affixes 1 and t stand for the, almost longitudinal and transverse orientation of the cellulose fibrils in the respective lamellae. The cellulose fibrils in the broad lamellae are oriented almost parallel to the long axis of the fibre (2°–20°) exhibiting only a slight increase in angle from middle lamellae to the lumen. In all the narrow lamellae the fibrils are oriented almost perpendicular to the cell axis (85°–90°).

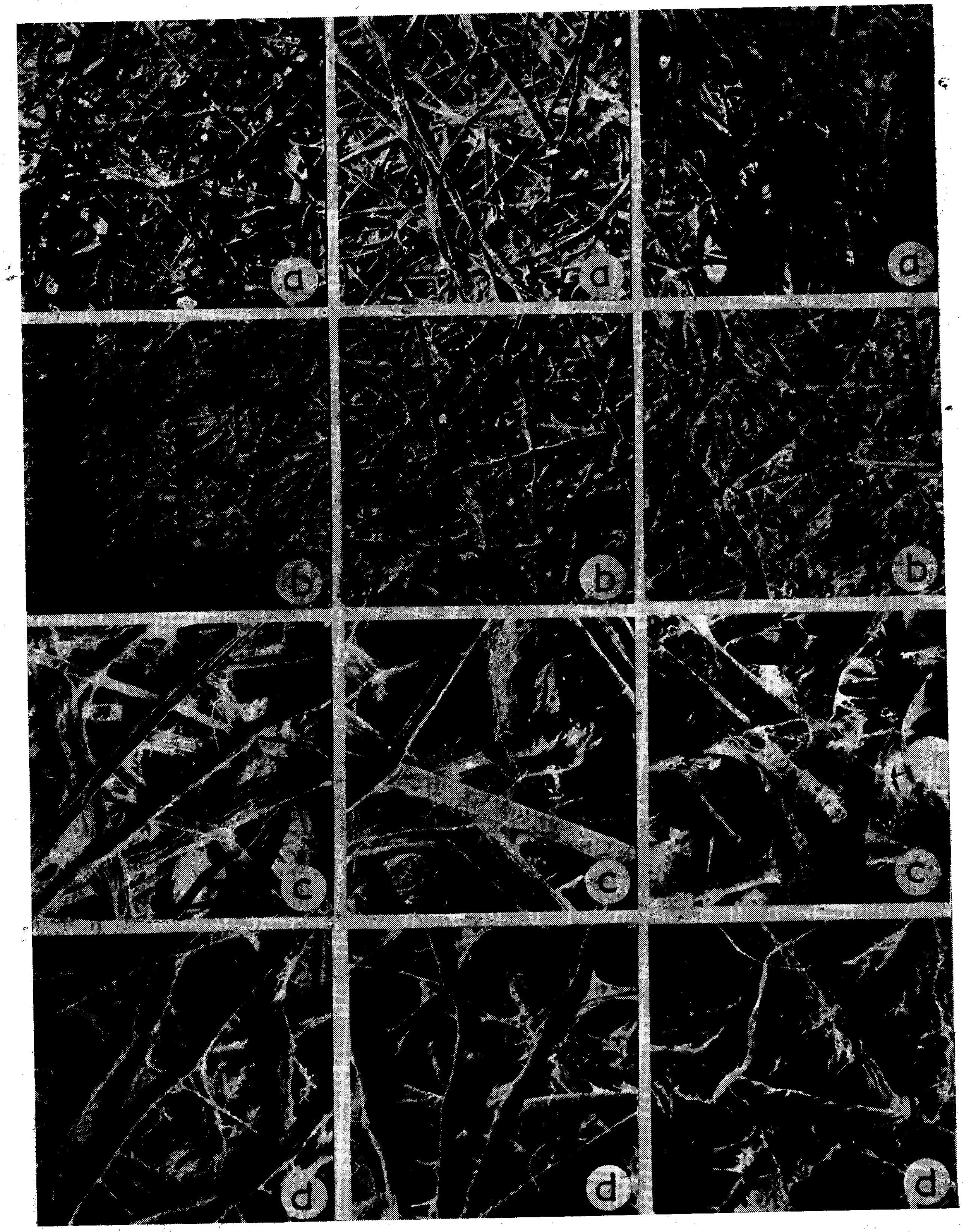
Studies on fracture of those fibres made by them showed that due to the small width of the narrow lamellae, the type of fracture seems to be mostly determined by the broad lamellae. The labile nature of the narrow lamellae is also indicated by the frequent separation of the adjacent broad lamellae in these regions.

The separation of the layers observed in the pulps of the three species is apparently also due to the same reason. The width of the layers have been found to vary from 0.12μ m to 2.7μ m for the broad layers and 0.06 μ m to 0.3μ m for the thin layers. Apparently thickness of these layers also contribute to the nature and type of separation of the layers. A study of the cross section of fibres of the three species shows that thickest walls with 6 to 9 layers thick and thin alternating layers are found in *M. baccifera* where of the fibre in *D. strictus* have the thinest walls. Only three layers can be distinguished in them, the inner most being only slightly thicker. In *D. hamil-*

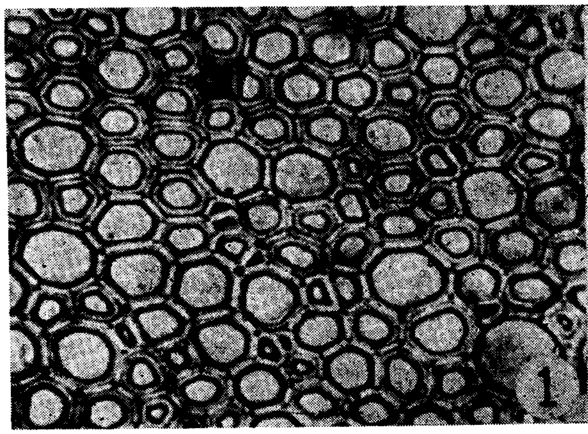


Cross sections of the hand sheets made from pulps beaten to different degrees of freeness (a-550, b–400, c-250 and d-100 ml. C.S.F. showing changes in fibre diameter and cell wall on beating (all x 400), **1-Dendrocalamus hamiltonii; 2-Dendrocalamus strictus; 3-Melocanna baccifera.**

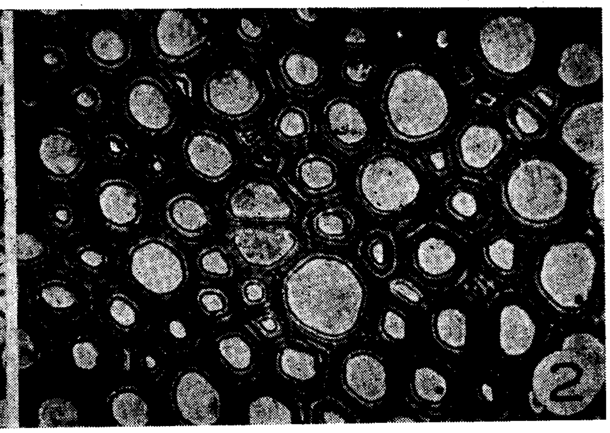
PLATE-II



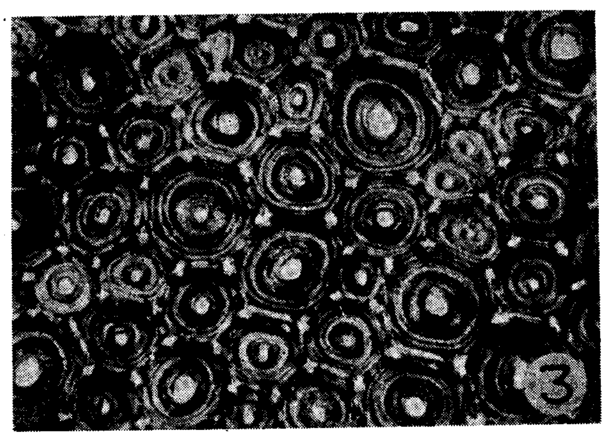
Electron micrographs of hand sheets made from pulps of three species of bamboos beaten to 550 (a and c) and 250 (b and d) ml. C.S.F., showing development of fibrillation and fissures on beating. 1-**Dendrocalamus hamiltonii**; 2- **Dendrocalamus strictus**; 3- **Melocanna baccifera.**



Dendrocalamus hamiltouii



Dendrocalamus strictus



Malocanna baccifera

Cross section of fibre vascular bundle of the three species of bamboos, showing differences in cross sectional dimensions of fibres as well as layering in the fibre walls (all x 400), 1-**Dendrocalamus hamiltonii** ; 2-**Dendrocalamus strictus** ; 3-**Melocanna baccifera.**

tonii on the other hand the fibres a comparatively thicker walled than *D. strictus*. Although only 3 layers are discrenable in this species also, the middle layer appears to be very much thicker than outer one. Further it is interesting to note that while in *M.baccifera* the cell wall layer are easily distinguishable even at a low magnification, these layers are not prominent in the other two species investigated. Whether this is due to differences in the relative thickness of the alternating layers requires to be investigated. The differences in the structure of fibres observed in the pulp sheets are apparently due to such inherrent differences in them. The variation in the sheet properties is greatly affected by the presence of loose layers surrounding the fibres, which evidently results in stiffness and lack of confirmability of the fibres. The differences, in the strength properties of pulp sheets of the bamboos may be due to the variations in the proportion of such fibres in them. It will be interesting to investigate whether the variations in the chemical nature of the lignin in different bamboos also related to such morphological differences (Singh and Bhola 1978). It is also interesting to note that although the trend for tensile strength and burst factor to increase with beating is similar in all the three species, the changes in the tearing strength are quite dissimilar. In *D. hamiltonii,* there is a continuous fall and in *M. baccifera* the trend is opposite while *D. strictus* after an initial rise tear strength falls with beating. These differences are probably due to variations in the stiffness of the fibres or the individual fibre strength of the fibres as evidenced by the loss of the outer shells of the walls which are more or less comparable to the multiply wood in coustruction. In this connection, it may be mentioned that Wangaard (1962) also observed a trend similar to that found in *M. baccifera* in some hardwoods having very thick walls. He found that in these woods there is a high degree of resistance to collapse and the associated opportunity for fibre to fibre bonding.

ACKNOWLEDGEMENT

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REFERENCES

1. Emerton, H.W., Page, D.H. and Hale, W.H. (1962). The structure of papers as seen in thin surfaces in "Formation and structure of paper" (E. d Bolam, F) pp. 53–99.
2. Krishnagopalan, A., Kutscha, N. P., Simard, G.L. (1975)– The effect of refining on the morphology and properties of bamboos paper. **IPPTA 12** : 9–19.
3. Monsalud, M.R. (1965)–Fibre characteristics of bamboos species in the phillipines. Paper submitted to the Conference on pulp and paper development in Africa and Near East Cario.
4. Parameshwaran, N., and Liese, W. (1976)-On the structure of bamboo fibres. **Wood Science and Technology 10** : 231–246.
5. Singh, Man Mohan, Bhola, P. P., Purkayastha, S.K. and Sharma, Luxmi (1975). Effect of beating variables on sheet formation of bamboo pulp. **IPPTA 14;** 178–185.
6. Singh, Man Mohan, Purkayastha, S. K., Bhola, P. P., Krishna Lal, & Swaran Singh, (1976 b)– Fibre morphology and pulp sheet properties of Indian bamboos. **Ind. For. 102** : 579–595.
7. Singh , Man Mohan & Bhola, P.P. (1978) - Chemical nature of soda Lignins and pulp sheet properties of Indian bamboos. Ind. For. 194:438–449.
8. Tono, T. Ono, K. (1962) - Researches on the morphological structure and the physical properties of bamboos fibres for papermaking. I. Relation between the behaviour of swelling and the morphological structure. II. The layered structure and its morphological transformation by acid treatment. **J. Jap. Wood Research, Soc. 8** : 238–244–249.
9. Wangaard, F. F. (1962)–Contributions of hardwoods fibres to the properties of kraft pulps. **Tappi 45** : 548–556.