Man Mohan Singh*
P.P. Bhola*
S.K. Purkayastha**
Laxmi Sharma**

Effect of beating variables on sheet formation of bamboo pulp

The effect of beating variables like consistency and temperature on strength development in bamboo pulp was studied. Variations in fibre morphology as well as orientation of the fibres in the hand sheets were also investigated. No significant difference was found in the strength properties of the hand sheets examined but significant difference in fibre dimensions was observed when the temperature was varied.

On beating, various cell wall layers of bamboo fibre open up leaving a gap between them. This gap not only increases the percentage of void area in the sheet but also does not allow the fibres to bind to a compact mass. This appears to be the main handicap of the bamboo fibres.

Introduction

Earlier work[1] with fractioned pulp of *Dendrocalamus strictus* showed that fibre dimensions accounts for 77 to 90% of the variation in strength properties namely breaking length, burst factor and tear factor. But when this investigation was extended to 12 different species of bamboo, it was found that sheet properties of various species of bamboo cannot be predicted from fibre dimensions or from chemical composition[2].

In order to investigate the factors responsible for the development of strength in bamboo pulp, the effect of beating variables like consistency and temperature were studied. The effect of these variables on fibre morphology as well as orientation of the fibres in the hand sheets were also investigated and related with the sheet properties. The results are likely to be useful in a better understanding of the sheet formation properties of bamboo pulp.

Material and Methods

Bleached bamboo pulp of *Dendrocalamus strictus* was beaten in valley beater at 15°C and 35°C keeping the consistency of the stock at 1.0%, 1.5%, 2.0% and 2.5%.

An arrangement to heat the pulp in the valley beater was rigged up. The temperature was achieved by circulating the water at controlled temperature through a copper pipe 1½" diameter immersed in the pulp. The position of the pipe was adjusted so as not to obstruct the flow of the pulp in the beater. (Table 1 to iv).

Standard sheets of 60 g.s.m. were made at 550, 400, 250 and 100 ml (C.S.F.) freeness and were dried using plates and rings. The sheets were conditioned at 25°C and 65% RH and were evaluated for physical properties.

For determining the fibre characteristics, a suspension of each pulp was prepared. A few fibres were placed on a slide mounted in water and data collected for every fibre and fibre fragment. Average fibre length was determined from 300 measurements. Average fibre diameter and lumen width were also determined from 300 measurements, from the maximum point of fibres and fibre fragments.

For studying the orientation of the fibres in the hand sheets, small pieces were embedded in epoxy resin following Kosakai's[3] embedding schedule for light microscopy with some modifications. Instead of Epon or Araldite a mixture of Dobeckot 505 C and the Hardener 750 was taken as the embedding medium. After dehydration the material was passed through acetone series and different mixture of acetone and the embedding medium. Finally the material was placed in a gelatin capsule filled with the pure embedding medium. The capsules were then left, uncapped at 60°C for 3–4 days for hardening. When the blocks were ready, 5–8μ thick sections were cut on a sliding microtome. The sections were placed on slides coated with 1.0% gelatin solution and dried at 40°C.

Man Mohan Singh, P. P. Bhola, S.K. Purkayastha, Laxmi Sharma
Forest Research Institute & Colleges, Dehra Dun.
*** Cellulose and Paper Branch**
**** Wood Anatomy Branch**

Table—I

Sheet properties of beaten pulp in valley beater at different consistencies and freeness at 15°C

Sheet properties	Un-beaten	1.0% consistency				1.5% consistency				2.0% consistency				2.5% consistency			
		550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml
Bulk (cc/g)		2.46	2.34	1.89	1.76	2.12	1.85	1.48	1.29	2.20	2.16	1.95	1.70	2.07	1.97	1.85	1.58
Breaking length (m)		2040	3460	4190	5300	3370	3740	4670	5810	2310	3900	4840	5450	3100	4000	5040	5250
Burst factor		11.2	20.4	25.3	35 8	16.5	24 3	35.0	37.4	14.1	24.2	33.1	36.2	16.3	25.0	31.1	36.0
Tear factor		97.5	104 8	94.2	82.0	103.5	102.2	68.5	53.5	118.8	122.4	102.4	87.2	108.8	102.2	93.5	89.1
Folding endurance (double folds)		12	26	78	66	20	41	97	114	8	53	85	177	18	42	134	148

Table–II

Average of fibre characteristics of beaten pulp in valley beater at different consistencies and freeness at 15°C

Fibere characteristics	Un-beaten	1.0% consistency				1.5% consistency				2.0% consistency				2.5% consistency			
		550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml
Fibre length (μ)	1709.7	1445.7	1377.1	1206.9	1094.0	1638.8	1461.5	1351.4	1298.4	1584.4	1414.3	1307.0	1195.5	1543.0	1441.4	1337.1	1202.6
Fibre diameter (μ)	14.235	14.186	14.817	14.846	15.409	15.016	15.197	16.152	17.217	14.337	15.759	16.014	16.805	15.624	16.423	17.819	18.005
Lumen diameter(μ)	2.505	2.552	2.207	1.896	1.792	2.289	2.001	1.814	1.523	2.153	1.869	2.007	1.761	2.510	1.932	1.812	1.523
wall thickness (μ)	5.865	5.820	6.315	6.480	6.810	6.360	6.600	7.170	7.845	6.090	6.945	7.005	7.530	6.570	7.245	8.010	8.235

Table–III

Sheet properties of beaten pulp in valley beater at different consistencies and freeness at 35°C

Sheet properties	1.0% consistency				1.5% consistency				2.0% consistency				2.5% consistency			
	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml
Bulk (cc/g)	1.95	1.72	1.69	1.29	1.98	1.58	1.54	1.41	2.03	1.56	1.31	1.28	1.87	1.67	1.26	1.12
Breaking length (m)	3250	3700	5090	4650	3320	3930	5140	5880	3350	4150	4750	4950	3340	4580	4640	4510
Burst factor	19.9	25.2	31.7	33.8	18.8	28.0	32.7	36.2	17.9	26.7	32.6	33.2	17.3	26.6	29.6	27.0
Tear factor	92.0	83.0	82.5	67.6	113.2	112.6	103.0	92.0	96.8	81.2	70.9	65.5	95.2	75.0	63.4	51.3
Folding endurance (double folds)	25	90	96	114	38	62	80	122	20	77	90	111	22	44	50	28

Table–IV

Average of fibre characteristics of beaten pulp in valley beater at different consistencies and freeness at 35°C

Fibre characteristics	Un-beaten	1 0% consistency				1.5% consistency				2.0% consistency				2.5 % consistency			
		550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml
Fibre length (μ)	1709.7	1491.5	1428.6	1407.1	1262.7	1613.0	1487.2	1390.0	1397.0	1600.2	1594.5	1437.2	1284.1	1594.5	481.5	1359.9	1289.91
Fibre diameter (μ)	14.235	16.587	16.413	17.211	17.541	16.099	6.599	16.210	17.192	15.955	16.106	16.427	17.664	15.896	16.055	17.640	17.388
Lumen diameter(μ)	2.505	2.037	1.912	1.508	1.241	1.972	1 689	1.812	1.526	1.756	2.264	1.760	1.475	2,574	2.125	2.159	1.960
Wall thickness (μ)	5.865	7.275	7.260	7.845	8.145	7.065	7.455	7.200	7.830	6.600	6.930	7.335	8.100	6.660	6.960	7.740	7.710

After drying these were stained in Iron-Alum Haematoxylin and mounted in the embedding medium. Photomicrographs were taken with a Zeiss microscope. Average width of the paper was determined from measurements taken at 5 different points from the sections. From the same points void areas were calculated from the portion of the imaginary line across the section not covered with fibres or debris.

Results and Discussions

In table I and III the results of the sheet properties at 15°C and 35°C are respectively recorded. Statistical analysis of the data reveals that both breaking length and burst factor increase with decreasing freeness whereas in tear factor there is no significant difference at 550 and 400 ml (C.S.F.) but it is significantly lowered at 250 and 100 ml (C.S.F.) (Table V). It was observed that there is no significant difference in case of both breaking length and tear factor when the consistency was varied from 1.0% to 2.5%, burst factor however showed a significant difference at 5% level of probability. The best strength was observed between 1.5 to 2.0% consistency (Table VI). Similarly there was no significant difference between 15°C and 35°C in breaking length and burst factor but tear factor gave significantly higher values at 15°C (Table VII).

In Tables II and IV the results of the fibre dimensions at 15°C and

Table-V

Mean values of strength properties of different freeness, their significance and bar-diagrams.

Strength properties	Freeness				Significance	Bar-diagram
	550 ml	400 ml	250 ml	100 ml		
Breaking length (m)	2992.8	3952.1	4789.0	5220.4	**	100>250>400>550
Burst factor	16.7	25.2	30.9	34.4	**	100>250>400>550
Tear factor	103.0	97.2	84.8	74.2	**	550 400 250 100

** ** **Significant at 0.1% level of probability.

Table-VI

Mean values of strength properties for different consistencies, their significance and bar-diagram

Strength properties	Consistency				Significance	Bar-diagram
	1.0%	1.5%	2.0%	2.5%		
Breaking length (M)	3969.6	4472.1	4213.5	4299.0	N.S.	
Burst factor	25.5	28.5	27.0	26.3	*	1.5 2.0 2.5 1.0
Tear factor	87.8	93.5	93.2	84.7	N.S.	

N.S. Not significant at 5% level of probability.

* Significant at 5% level of probability.

Table-VII

Average values of strength properties under different temperatures pooled over all consistencies and freeness along with their significance

Strength Properties	Beaten at		Significance	Bar-diagram
	15°C	35°C		
Breaking length (m)	4147.6	4329.6	N.S.	
Burst factor	26.5	27.1	N.S.	
Tear factor	95.5	84.1	**	15°C>35°C

** Significant at 1.0% level of probability.

25°C are respectively recorded. Analysis of the data showed that as expected the fibre length decreased with increase in beating but both diameter and wall thickness followed an opposite trend (Table VIII). With the change in consistency although there is a significant difference in fibre characteristics there is no definite pattern (Table IX).

Higher temperature on the other hand reduces cutting of fibres and increases flattening and also increase the wall thickness of the fibres as will be evident from Table X.

The three fibre characteristics namely fibre length, fibre diameter and wall thickness are observed to be significantly correlated with each other and their correlation coefficients are given below :-

Fibre length Vs diameter = -0.375*

Fibre length Vs wall thickness -0.477**

Fibre diameter Vs wall thickness =+0.976***

Though there is a good correlation between the fibre dimensions and strength properties when ll the data are pooled (Table), the

Table–VIII

Average values of fibre characteristics of different freeness pooled over all consistencies and temperatures along with the significance and bar-diagram

Fibre characteristics	Unbeaten pulp	Freeness				Significance	Bar-diagram
		550 ml	400 ml	250 ml	100 ml		
Fibre length (μ)	1709.7	1564.4	1461.5	1349.9	1251.3	***	550>400>250>100
Fibre diameter (μ)	14.235	15.465	15.930	16.545	17.145	***	100>250>400>550
Wall thickness (μ)	5.865	6.555	6.960	7.350	7.770	***	100>250>400>550

***Significant at 0.1% level of probability.

Table–IX

Average values of fibre characteristics of consistencies pooled over all the freeness and temperatures, along with the significance and bar–diagram.

Fibre characteristics	Unbeaten pulp	Consistency				Significance	Bar–diagram
		1.0%	1.5%	2.0%	2.5%		
Fibre length (μ)	1709.7	1338.5	1454.3	1427.1	1405.7	* * *	1.5 2.0 2.5 1.0
Fibre diameter (μ)	14.235	15.870	16.215	16.140	16.860	* *	2.5 1.5 2.0 1.0
Wall thickness (μ)	5.865	6.980	7.185	7.065	7.395	*	2.5 1.5 2.0 1.0

Table–X

Average values of fibre characteristics of different temperatures pooled over all consistencies and freeness along with significance and bar–diagram.

Fibre characteristics	Unbeaten pulp	Beaten Temperature		Significance	Bar–diagram
		15°C	25°C		
Fibre length (μ)	1702.7	1368.7	1444.3	* * *	35°C > 15°C
Fibre diameter (μ)	14.235	15.853	16.687	* * *	35°C > 15°C
Wall thickness (μ)	5.865	6.945	7.390	* * *	35°C > 15°C

Table–XI

Values of correlation between different fibre characteristics and strength properties

Fibre characteristics	Strength properties		
	Breaking length	Burst factor	Tear factor
Fibre length	—0.675***	—0.740***	0.454**
Fibre diameter	0·697***	0.689***	—0.667***
Wall thickness	0.765***	0.778***	—0.556***

relationship appears to be a chance one. As already stated earlier there is highly significant difference in fibre dimensions of pulp beaten at 15°C and 35°C while this difference is not reflected in the strength properties. Evidently factors other than fibre dimensions play a more important role in strength development. The other factors which could possibly be responsible for the differences in the strength properties are fibre orientation and interfibre bonding in the sheets.

To investigate both these aspects, sections of the hand sheets, embedded in epoxy resin, were examined under the microscope (Plate I Fig. A to H). As expected the thickness of the papers and the percentage of the void area of the paper decrease with increased beating (Table XII). The minor discrepancies observed may be due to the variations in the thickness of hand sheets or be due to the fact that only a small portion of the sheet was examined.

From Table XII, it will be observed that the percentage of the void area at different consistencies and temperatures, remain more or less similar at different freeness. This probably is the reason for lack of significant differences in strength properties. Increase in the compactness of the sheet with beating is apparently due to the mechanism of surface tension as proposed by Campbell[4]. The individual fibres are drawn together and the points of contact are enlarged resulting in increased bonded areas.

At higher magnification it is observed that various wall layers open up with increased beating thus resulting in more exposed surface area. This indicates that fibrillation also takes place though it is not clearly discernible with a light microscope. Krishan Gopalan *et al*[5] have clearly demonstrated it in their study of the bamboo pulp with electron microscope.

It is interesting to note that the various cell wall layers (Plate I Fig. E to H) open up leaving a gap between them (Plate A to D). This gap not only increases the percentage of void area in the sheet but also does not allow the fibres to bind to a compact mass. This also reduces the chances of hydrogen bonding. This appears to be the main handicap of the bamboo fibres. Further work to investigate this concept is in progress.

Acknowledgement

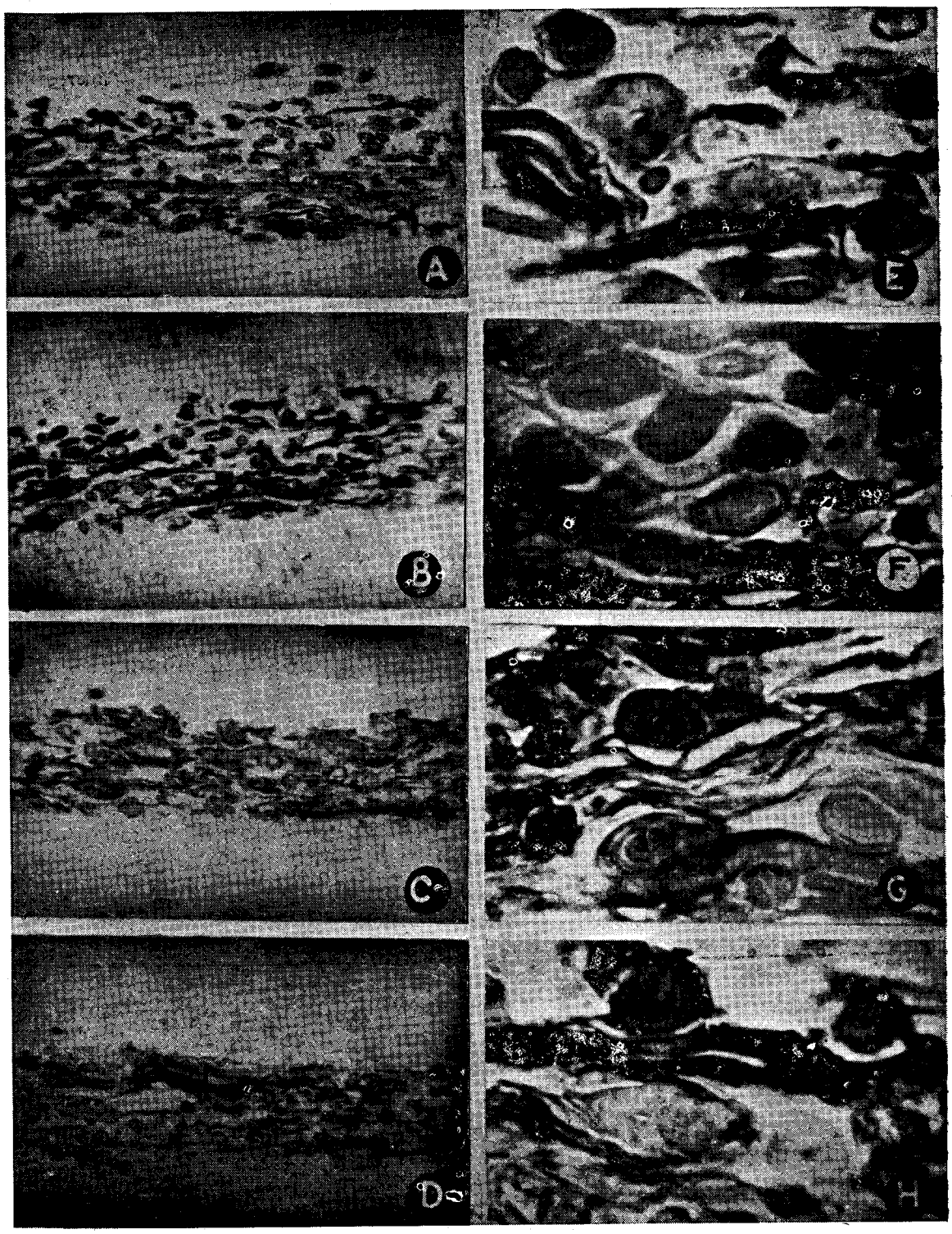
Thanks are due to S/Shri D. S. Phalke and Swarn Singh of the Statistical Branch of the Institute for carrying out the statistical analysis.

Table–XII

Valuation in the thickness of the pulp sheet and void spaces with beating at different temperatures and consistency.

	1.5% consistency				2.5% consistency			
	550 ml	400 ml	250 ml	100 ml	550 ml	400 ml	250 ml	100 ml
Thickness of sheet at 15°C (μ)	176.6	170.8	130.0	117.3	127.5	126.6	109.0	100.3
Void spaces at 15°C (%)	42.5	40.0	36.6	32.0	37.3	36.2	27.3	27.9
Thickness of sheet at 35°C (μ)	166.6	145.3	110.2	99.5	129.2	129.2	96.9	62.0
Void spaces at 35°C (%)	41.8	40.9	35.5	20.9	42.9	36.2	31.6	24.7

Plate I



Effect of Beating on bamboo (*Dendrocalamus strictus* Nee.) pulp

Explanation of the Plate

A—D Cross sections of pulp sheets showing gradual increase in compactness with reduction in width and void spaces with beating. X 65. A–550, B–400, C–250, and D–100 ml (C.S.F.). Pulp beating at 1.5% consistency at 15°C.

E—H The same at higher magnification (X 1000) showing changes in the fibre structure with beating, Note the opening out of the different layers of the cell walls and increase in the amount of debris, especially in G & H.

Reference

1. Man Mohan Singh, S.K. Purkayastha, P.P. Bhola and Laxmi Sharma 'Influence of Variation of Fibre Dimensions and Parenchyma Proportion on sheet Properties in Bamboo' *Indian Forester, 97*, p. 412-421, 1971.
2. Man Mohan Singh, S.K. Purkayastha, P.P. Bhola and Krishna Lal 'Fibre Morphology and Pulp Sheet Properties of Indian Bamboo'. Paper presented at Forests Products Conference held on Dec. 11-13, 1974 at Forest Research Institute & Colleges, Dehra Dun.
3. Hastume Kosakai–Epoxy embedding, sectioning and staining of plant material for light microscopy. *Stain Technology 48*, 1973.
4. H.N. Emerton 'Fundamentals of the Beating Process' published by the Bristish Paper & Board Industry Research Association, Kenley 1957, p. 93.
5. A. Krishnagopalan, Norman P. Kutscha and Gerald L. Simar 'The effect of refining on the morphology and properties of Bamboo Paper' *Ippta 12* p. 9-19, 1975.