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A Study of the Strength Development of Bamboo Unbleached Pulps

Bamboo contains 30-40 per cent of parenchyma material which contributes very little to the strength properties of paper. It only adds to the pulp as a filler. Attempts were made to separate the fines fraction, refine them separately and blend with the fibre fraction assuming that such pulps would give better strength properties than that of whole pulp. Studies were carried out regarding the effect of additives.

The results indicate that the fibre fraction gives considerably higher strength properties than that of whole pulp. Addition of 0.4 per cent guar gum (daicol) to fibre fraction gives improved breaking length, burst factor and folding endurance by 17.4%, 23.5%, 22.5% respectively compared to the whole pulps strength improvement of 10.4%, 15.6% and 75% for breaking length, burst factor and folding endurance respectively. Over all properties of combinations of fines and fibres with daicol also show improvement but not to the extent of fibre fraction. Pulps prepared after refining separately and blending together of fibre and fines fraction do not give any improvement over that of whole pulp.

INTRODUCTION

In India bamboo is the chief raw material used for manufacturing variety of papers like printing paper, writing paper, wrapping paper etc., i.e. same raw material is used to get different end products meant for different uses which require different criteria and properties.

A particular raw material suitable for certain grade of paper may not be suitable for other grades of paper. But there are means by which we can modify the pulps obtained from the same raw material to suit different end products.

To start with, in cooking itself, by varying chemicals, temperature etc. different types of pulps can be obtained (1), Also by adding different beater additives pulps can be modified. There is yet another way too. Morphological and chemical analysis of bamboo reveal, that 30-40 percent parenchyma cells are present which constitute a significant part. These fines do not contribute any thing or very little to the strength properties. So fines content can be adjusted or removed completely to obtain better pulps for high grade papers. Before making paper, the pulp is subjected to mechanical action like beating and refining. During beating or refining many things may happen to the fibres. They may be swollen, broken or cut or may be brushed and internal or external fibrillation may take place. These may occur simultaneously or individually or in groups, depending upon the machinery used. But what happens to the fines fraction (Parenchyma) which is present to the extent of 30—40 per cent of the total tissues present in the bamboo ? There is very little or no information at all in this regard. It is natural to know as to what happens to these cells or in what way they respond to the mechanical actions and what are the contribution of these tiny cells to the over-all properties of paper. There are so many unanswered questions. Therefore, an attempt has been made to open sesame — to know about these fines and their behaviour.

Bamboo is composed of tissues divided in two broad classes, (i) Prosenchymatus and (ii) Parenchymatus. Long thick walled fibres arranged in clusters of fibrovascular bundles are the components of the prosenchymatus tissues which give strength and toughness to bamboo; whereas the parenchymatus tissue is composed of tiny nearly isodiametric cells whose function is conduction and storage of food material

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TABLE I

CHEMICAL ANALYSIS OF FIBRES AND PARENCHYMA CELLS OF BAMBOO D. STRICTUS

(Percentage value based on dry weight of tissue material analysed)

Constituent	Bottom inter-fibres -nodes %	Parenchyma cells %	Upper internodes fibres %
Solubility in :			
Cold water	0.76	1.14	1.03
Hot water	3.75	4.26	3.12
NaOH 1%	12.58	21.30	17.81
Ether	0.05	0.05	0.33
Alcohol benzene	1.18	1.66	0.88
Ash	0.71	1.27	1.35
Cellulose (C & B)	63.23	51.33	61.41
Lignin	28.66	27.27	23.30
Alfa cellulose	53.93	39.35	46.62
Beta cellulose	5.78	7.68	6.59
Gamma cellulose	3.50	4.35	8.20
Pentosans	15.18	19.67	19.42

elaborated by plants. Parenchyma tissue is between 29 — 45 percent of the total tissue by weight depending upon the position of the cells in the bamboo clum (2). Chemical analysis of these tissues is given in Table No. I (2). Typical bamboo shows the following tissues in it (3) Fig. No. 1.

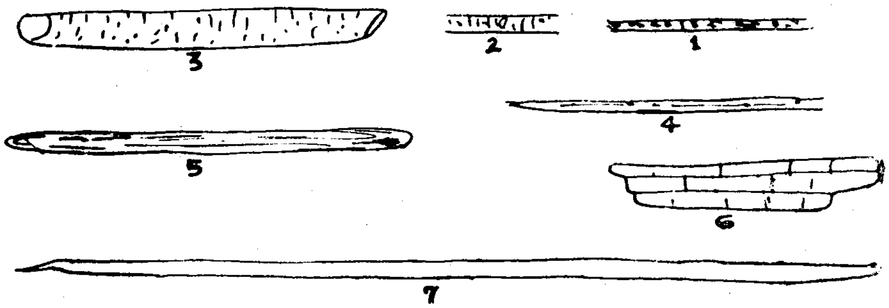

FIGURE 1: BAMBOO CEPHALOSTACHYUM PERGRACILE MUNRO

1. Short, tracheid like cell, x 270, 2. Pitted short, tracheid like cell, x 270 with spiral thickening, 3. Pitted vessel element x 90, showing areas of contact with longitudinal parenchyma, 4. Short fibre, x 90, notched at upper end, 5. Long parenchymatus cell, x 90, 6. Cluster of parenchymatus cells x 90, from ground tissue of the culm, 7. Fibre, x 90.

1. Short tracheid like cells.
2. Pitted short tracheid like cells with spiral thickening.
3. Pitted vessel element.
4. Short fibre.
5. Long parenchymatus cells.
6. Cluster of Parenchymatus cell.
7. Fibre.

The amount of Parenchyma and ray cells in soft wood and hard wood is comparatively less compared to bamboo; 7.5 percent in case of soft woods and about 20 to 25 percent in case of hardwoods (4).

Parenchyma cells are thin walled polygonal structures differing in composition physical as well as chemical from plant to plant. Parenchyma cells contain starch grains and amides. Many parenchyma cells also contain phenols, tannins and some mineral substances[5]. Chemical composition of fines vary markedly from the other fractions in fibre fractionation. These fines which are made up of parenchyma cells, ray cells and some broken fibres are less desirable from the paper making, stand point than the fibres[6]. For example the fines in bleached sulphite pulp contains approximately ten times as much resinous material and a much greater amount of ash — hence inorganic matter like silica than the whole pulp. They have a higher per cent of degraded cellulose material, than the longer fibres and this is manifested in an increased alkali solubility, increased copper number and decreased viscosity. They are considerably inferior to the long fibres with respect to bleachability. Even the fines of esparto pulp have a much higher bleachability than the rest of the fibres[6]. Fines are very much undesirable in chemical wood pulps if present too high per cent since they reduce the colour and the strength of the pulp and tend to produce pitch trouble on the paper machine[6]. The exact amount of fines in pulp depends upon the method of chip preparation cooking bleaching and pulp washing operations. After studying the composition of bamboo it was felt that if fines (parenchyma cells etc.) could be removed then the resultant pulp might give improved properties compared to the whole pulp and could be used to manufacture high grade papers like drawing, kraft and sack paper etc. It was also felt that if the separated fines could be refined separately and blended with the long fibre fraction, then the over all properties of the pulp might be more than that of the whole pulp. Hence the main theme of these experiments was to separate the fines from the whole pulp and to study the strength properties of the sheets with different combinations.

EXPERIMENTAL

Laboratory cooked pulps and mill cooked pulps were used in these experiments.

Laboratory and Mill pulps were prepared using flowered sound bamboos chiefly consisting of Bambusa arundanacea and some Dendrocalamus strictus.

In laboratory, pulps were prepared in a rotating digester, electrically heated with a capacity of 16 litres tumbling at 2. r.p.m. In each cook, hand sorted chips equivalent to 2.0 kg. on oven dry basis were used. Mill cooked pulps were obtained by cooking the chips in indirectly heated, stationery digester of 80 m^3 capacity. The cooking conditions used in the laboratory experiments and in the mill are given below :

	Laboratory pulp	pulp Mill
Chemicals, %	18-18.5	18-18.5
Steaming time, hrs.	2	1½ to 2.0
Cooking time, hrs.	1 to 1½	1½
Cooking temp., °C	160	165
Bath ratio	1:2.5	1:2.5

The pulps were refined hot in Sprout Waldron disc refiner to get uniform pulps. Pulps obtained in the laboratory, after refining were washed free of alkali in the hydra-extractor and the consistency was increased to 26-28%. After mixing and proper sampling moisture and found and the yield was determined. The average yield was 55.5 per cent and permanganate number (40 mil) 22.3.

The mill pulp samples were collected after washing in the four stage brown stock washer and screening through centrifugal and tube screens. The average yield was 50 per cent and permanganate number (40 ml) 24.0. The pulps were free from shives and specks.

These pulps were used for further experiments.

SEPARATION OF FINES

A number of trials were made to separate out the fines on large scale by using different methods. After many trials the following methods was employed.

A fractionation chamber of 200 litre capacity with a cage of 40 mesh wire, a suction pump and a Kalle leaf filter with a tank with suitable connections were used to separate the fines. A fine strong, durable, nylon cloth with 0.4 second per 100 ml porosity was fixed on the filter leaves. The diagram is given in fig. 2.

and sampling the moisture contents of the fines and the fibres were found out and the yields were determined.
Microscopic examination of fines and fibre fraction revealed that the fines

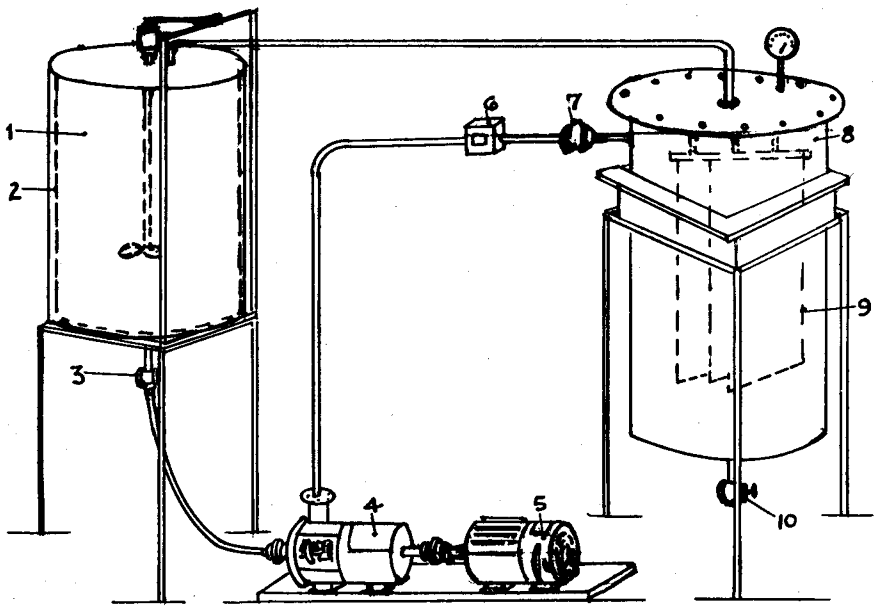

FIGURE 2: FRACTIONATION EQUIPMENT

1. Fractionation chamber, 2. 40 mesh wire cage, 3. Valve, 4. Suction pump, 5. Motor, 6. Observation point, 7. Valve, 8. Kalle filter tank, 9. Kalle filter leaves, 10. Valve.

The fractionation was carried out in batches for 15 to 20 minutes. Pulp equivalent to 1 kg. on oven dry basis was used in each batch. The pulp was diluted to about 1 per cent consistency in the fractionation chamber and stirred continuously to maintain uniformity and keep the fines and fibres loose. At that time the suction pump was started. The material passing through the wire mesh was sucked and collected on the nylon cloth fixed on the filter leaves. The water was recirculated to maintain constant level in the fractionation chamber. When the clear water coming through the observation point, was observed, the fractionation was stopped. The fines deposited on the filter leaves were collected and the consistency was increased to about 20 per cent by filtering the contents through a buckner funnel. The fibre fraction from the fractionation chamber was collected separately and the excess water was removed in a hydra extractor. After proper mixing

contain not more than 5 per cent fibres and the fibre content contain not more than 5 per cent fines content. The results indicated that the fractionation of the pulps in the fractionation equipment was quite satisfactory. The results are given in Table II. Sufficient amount of fibres and fines were collected for carrying out the present studies.

TABLE NO. II
FIBRE FRACTIONATION

	Mill cooked bamboo pulp	Laboratory cooked bamboo pulp
Fibre fraction on whole pulp %	62.75	64.16
Fines on whole pulp %	37.25	35.34

Different combination of pulp were evaluated using the Sprout Waldron disc refiner and the Valley beater. In refining the pulp the consistency was maintained at 5 per cent and the refining was carried out at different disc clearances. In beating, in Valley beater air dried pulp equivalent to 360 gms on oven dry basis was used, maintaining the consistency at 1.56 per cent. The same way as described above, the fines were also treated. The combinations tried were as under :

Set I :

a) Whole pulp at five different slowness levels.
b) Fibre fraction at five different slowness levels.
c) Fines unrefined, added to the fibre fraction at five different slowness levels, in the same proportion as present in the whole pulp.
d) Fines refined, to different slowness levels, added to the fibre fraction of a particular slowness level.
e) Fines of highest slowness level added to the fibres of different slowness levels.

The results are recorded in Table III.

Set II :

To know the effect of refining on fibre fraction and fines fraction, like drainage time and slowness, few experiments were carried out using disc refiner. After refining the pulps were fractionated as described in the previous paras. The results are given in Table IV.

Set III : Use of additive

To study the effect of guar gum (diacol) a few experiments were carried out. Pulps were refined to one slowness level in the disc refiner and used in the combinations mentioned below using 0.40% Daicol, 0.6% Rosin and 2.0% Alum on pulp basis in the sequence Rosin — Daicol — Alum.

a) Whole pulp
b) Fibre fraction
c) Fibre fraction plus fines unrefined
d) Fibre fraction plus fines refined.

Hand sheets in all the above sets were prepared on British Sheet making machine and after conditioning, the sheets were tested for strength properties using mostly TAPPI standard methods. Pulp evaluation results are given in Table V & VI and in Fig. 3 to 13.

TABLE III
STRENGTH PROPERTIES OF PULP — REFINED IN DISC REFINER

Particulars	Whole pulp Initial °SR-15.0					Fibre fraction Initial °SR — 10.0					Fibre fraction + fines unrefined					Fibre refined to one °SR + fines refined to diff. °SR				Fibre refined to diff. °SR + fines refined to one °SR		
Clearance, microns	457	279	229	128	127	254	203	127	76	25	—	—	—	—	—	229	127	76	25	—	—	—
Final freeness °SR	20	22.5	41.0	62.5	63.5	14.0	16.0	26.5	29.5	50.5	29.5	26.0	62.0	71.0	76.5	65	65.5	69.5	72.5	16,75,60	25,75,70	45,72.5,75
																74.0	74.0	74.0	75.0			
Drainage time, Scs.	9.5	10.7	11.7	12.3	13.2	9.7	9.9	10.5	12.4	24.0	11.2	12.1	13.6	14.1	26.6	23.1	23.7	23.4	24.4	8.3	12.0	24.4
Basis wt. g/m^2	60.3	59.7	59.4	57.5	58.3	54.5	57.6	57.5	56.3	58.6	64.0	61.5	65.7	63.7	60.3	60.8	58.0	59.9	58.8	56.9	58.7	58.8
Bulk, cc/g.	2.17	2.15	2.05	1.97	1.91	2.39	2.32	1.98	2.00	1.77	2.20	2.15	1.93	1.81	1.74	1.83	1.85	1.64	1.61	1.84	1.72	1.61
Breaking, length, km.	2.47	2.61	2.84	3.43	3.53	2.80	3.32	4.33	4.98	5.61	2.39	2.26	2.21	3.17	3.87	3.18	3.71	3.99	4.24	3.27	3.75	4.24
Tear factor	171.6	177.5	176.6	187.9	164.5	203.4	236.1	215.8	202.6	162.9	159.3	154.4	149.1	144.5	132.6	—	128.5	123.6	120.4	215.7	204.1	120.4
Burst factor	18.1	19.4	22.9	26.4	26.1	20.1	26.4	36.2	37.1	43.0	18.3	18.9	18.3	26.4	29.5	24.5	30.7	33.1	32.2	34.6	31.2	33.2
Double folds	26	32	56	172	158	38	76	423	817	2280	24	33	22	63	123	56	182	244	448	58	152	448
Strength, Index	1638	1731	1919	2228	2113	1862	2272	2712	2798	2865	1591	1643	1541	1900	2041	1673	2073	2136	2197	2107	1385	2197

TABLE IV SLOWNESS AND DRAINAGE VALUES OF DIFFERENT FRACTION OF UNBLEACHED PULP

Disc Clearance	Whole pulp		Fibre fraction		Fines fraction	
Microns	Slowness °SR	Drainage time seds.	Slowness °SR	Drainage time seds.	Slowness °SR	Drainage time seds.
Unrefined	19.0	7.2	10.5	8.0	50.0	9.0
457	26.0	7.6	11.0	7.7	—	—
279	51.0	8.5	12.5	6.5	81.0	95
229	59.0	9.4	11.5	6.4	81.0	95-100
178	62.5	11.0	12.5	7.1	81.0	120
127	70.8	12.8	12.5	7.3	80	120-130

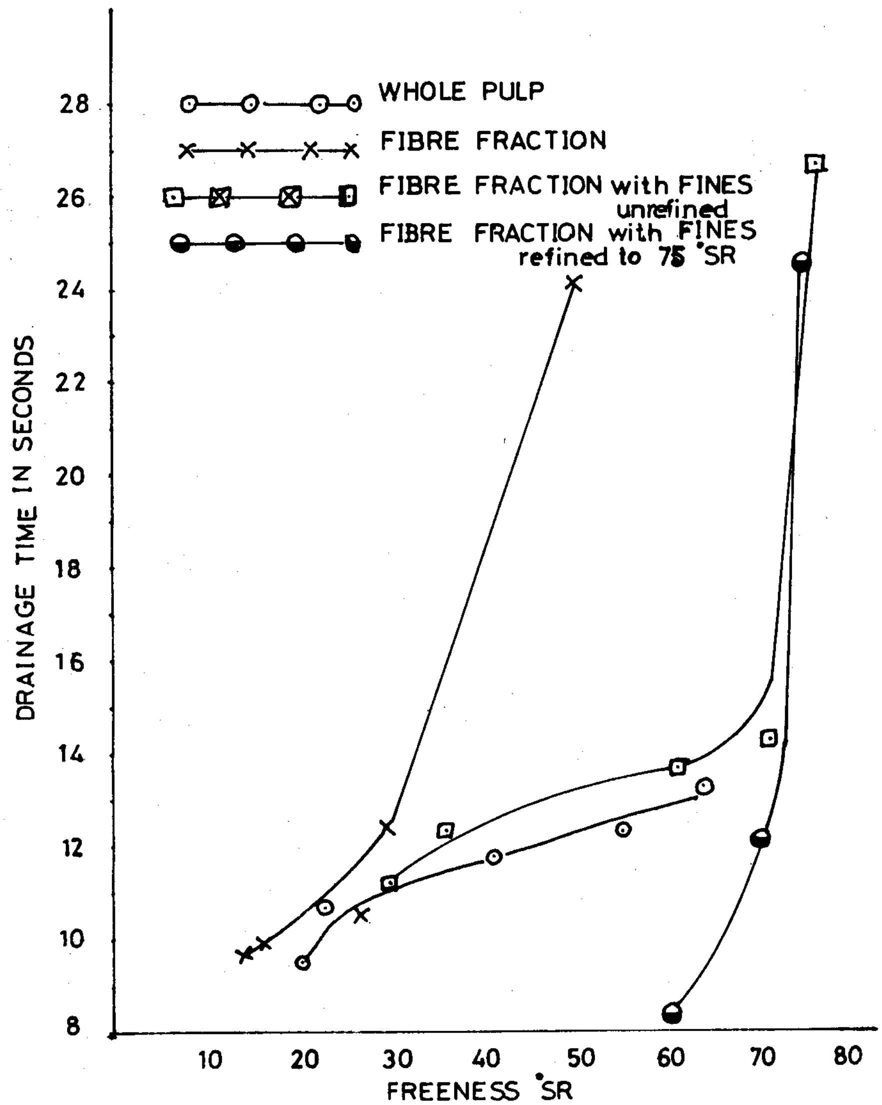

FIGURE 3 DRAINAGE TIME VS. SLOWNESS

OBSERVATION AND DISCUSSION

1. During refining of the pulps in the Sprout Waldron disc refiner it was observed that as the clearances between the plates of the refiner were reduced, the pulps obtained have higher degree of slowness with the increase in the drainage time on the British Sheet Making Machine. In case of whole pulp as the slowness increases gradually from 20 to 63.5 °SR the drainage time increases from 9.5 to 13.2 seconds (Fig. No. 3). But in case of fibre fraction a sharp rise in drainage time could be observed for a corresponding small change in slowness from 30 to 50 °SR compared to that of whole pulps. Same pattern of abrupt rise in drainage time could be observed with different combinations of fibres and fines. This gives an indication as seen in fig. 3 that drainage time and slowness do not have a linear relation. The strength properties are related with drainage time and also bulk instead of slowness.

Generally all properties increase as the drainage time increases in all combinations and as the bulk decreases, except in the case of tear factor which after an initial increase, decreases.

In Set I where whole pulp, fibre fractions and fines fractions were tested under different conditions as given in 'a' to 'e', the following observations could be made (Fig. 4 to 8).

Bulk :— As the drainage time has increased from 9.5 seconds to 13.2 seconds bulk has decreased from 2.17 to 1.91 in 'a' from 2.39 to 1.77 in 'b' when the drainage time has increased from 9.7 to 24.0 seconds; in 'c' bulk has decreased from 2.20 to 1.74 for 'a' change of drainage time from 11.2 to 26.6 seconds : in 'd' from 1.83 to 1.61 for a change of drainage time from 23.2 to 24.4 seconds; and in 'e' from 1.84 to 1.61 for a change of drainage time from 8.3 to 24.4 seconds. The results have been shown in Fig. No. 4.

Breaking Length : Breaking length has increased from 2.47 to 3.53 km. in 'a'; from 2.8 to 5.61 km in 'b'; from 2.39 to 3.87 km in 'c'; from 3.18 to 4.24 km in 'd' and from 3.27 to 4.24 in 'e' for a corresponding change in drainage time as discussed in Bulk. The results have been shown in Fig. 5.

Tear factor : Tear factor has increased from 171.6 to 177.5 between 9.5 to 10.7 seconds drainage time and then decreased to 164.5 for a drainage time of 13.2 seconds in 'a'. In 'b' tear factor has increased from 203.4 to 236.1 between 9.7 & 9.9 seconds drainage time and then decreased to 162.9, when the drainage time was 24.0 seconds. In 'c' tear factor has decreased from 159.3 to 132.6 when the drainage time has increased from 11.2 to 26.6 seconds. In 'd' tear factor has decreased from 128.5 to 120.4 for an increase of drainage time 23.7 to 24.4 seconds and in 'e' tear factor has decreased from 215.7 to 120.4 when the drainage time varied between 8.3 to 24.4 seconds. The results have been shown in Fig. 6.

Burst factor : Burst factor has increased from 18.1 to 26.1 in 'a'; from 20.1 to 43.0 in 'b'; from 18.3 to 29.5 in 'c'; from 24.5 to 33.2 in 'd'; from 24.6 to 33.2 in 'e' for a corresponding increase in drainage time. The results have been shown in Fig. 7.

Folding endurance : Folding endurance (double fold) has increased from 26 to 158 in 'a'; from 38 to 2280 in 'b'; from 24 to 123 in 'c'; from 56 to 448 in 'd' and from 58 to 448 in 'e'.

Strength Index : Strength Index is calculated using the formula — 100 $\times$ (Burst factor $\times$ tear factor $\times$ log fold)$^{1/3}$ Strength index has increased from 1638 to 2113 in 'a'; from 1862 to 2865 in 'b'; from 1591 to 2041 in 'c';

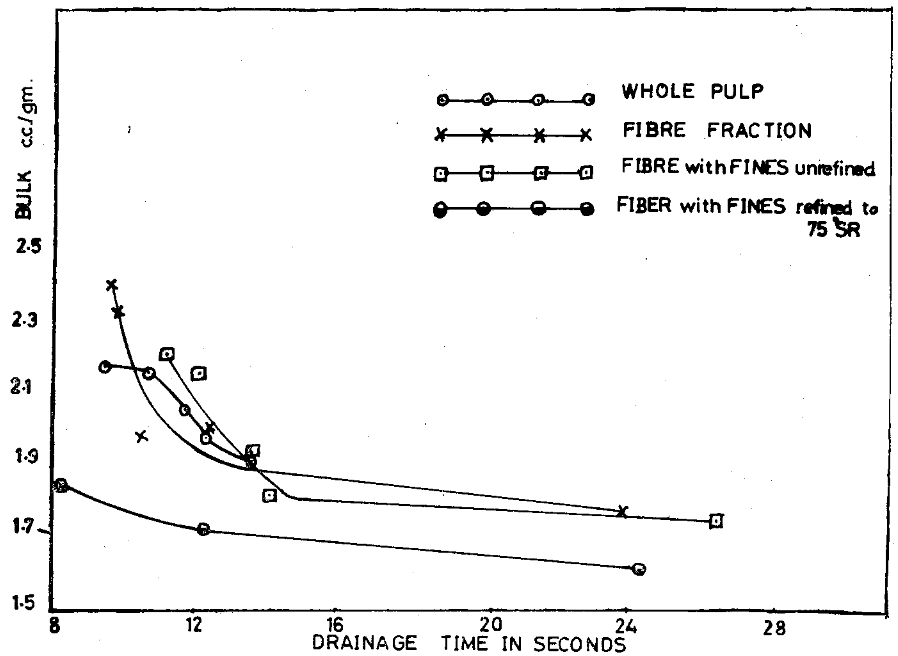

FIGURE 4 DRAINAGE TIME VS. BULK

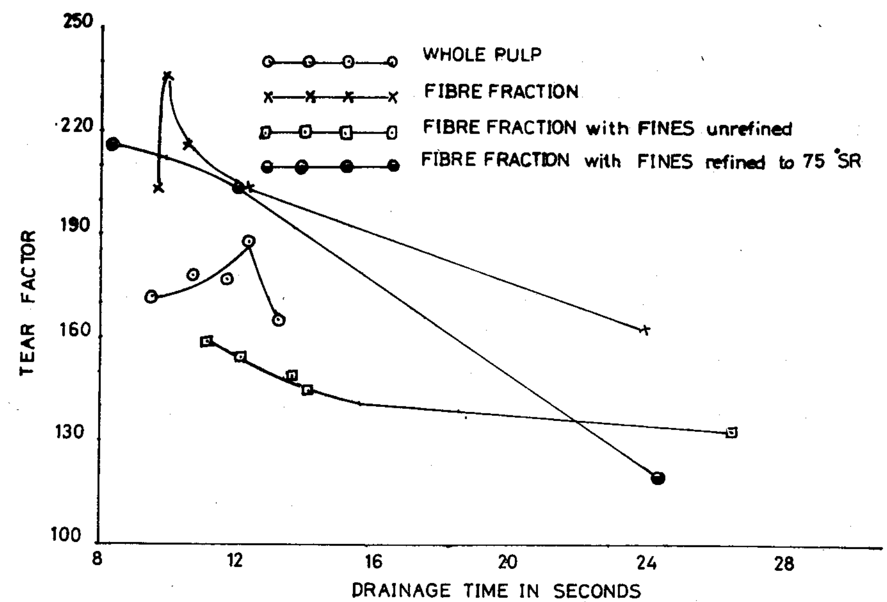

FIGURE 6 DRAINAGE TIME VS. TEAR FACTOR

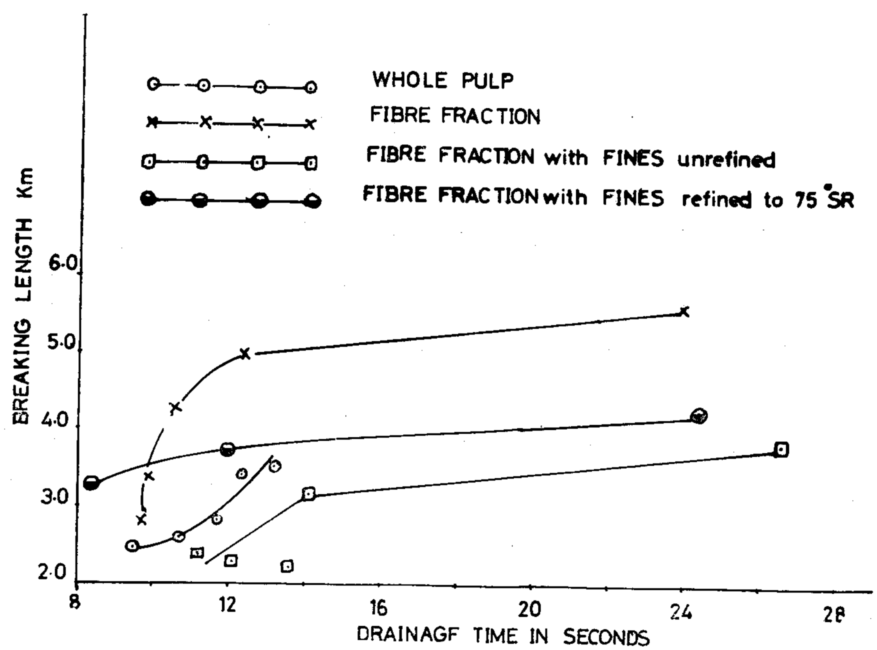

FIGURE 5 DRAINAGE TIME VS. BREAKING LENGTH

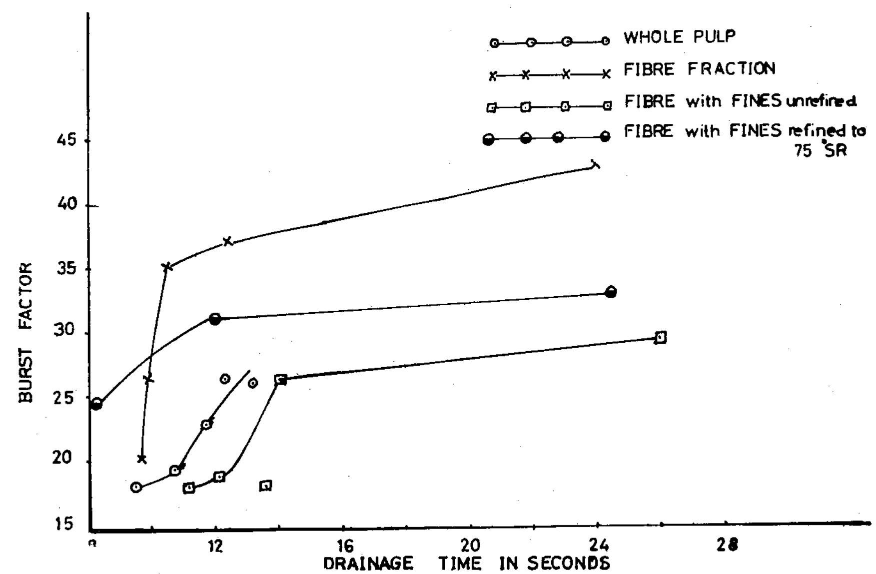

FIGURE 7 DRAINAGE TIME VS. BURST FACTOR

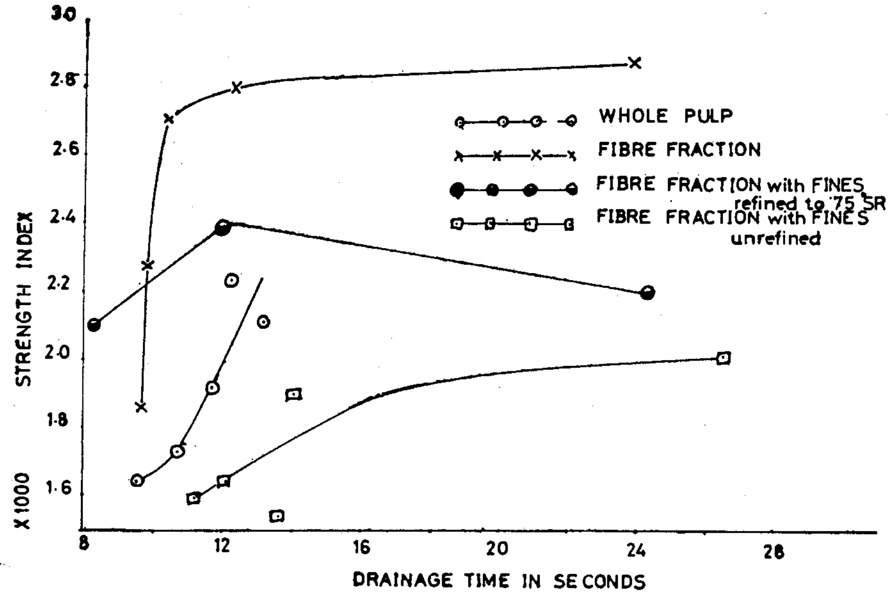

FIGURE 8 DRAINAGE TIME VS. STRENGTH INDEX

from 1672 ta 2197 in 'd' and from 2107 to 2197 in 'e'. The results have been shown in Fig. 8.

The strength properties studied with respect to bulk are given in Fig. No. 9, 10, 11 and 12.

When the strength properties are studied with respect to drainage time, fibre fraction gave considerably higher overall properties than whole pulp. Fibre fraction refined to different slowness blended with fines refined to one slowness also gave slightly better strength than whole pulp. But when the strength properties are studied with respect to bulk, the results show that except fibre fraction no other combination gave better strength than the whole pulp.

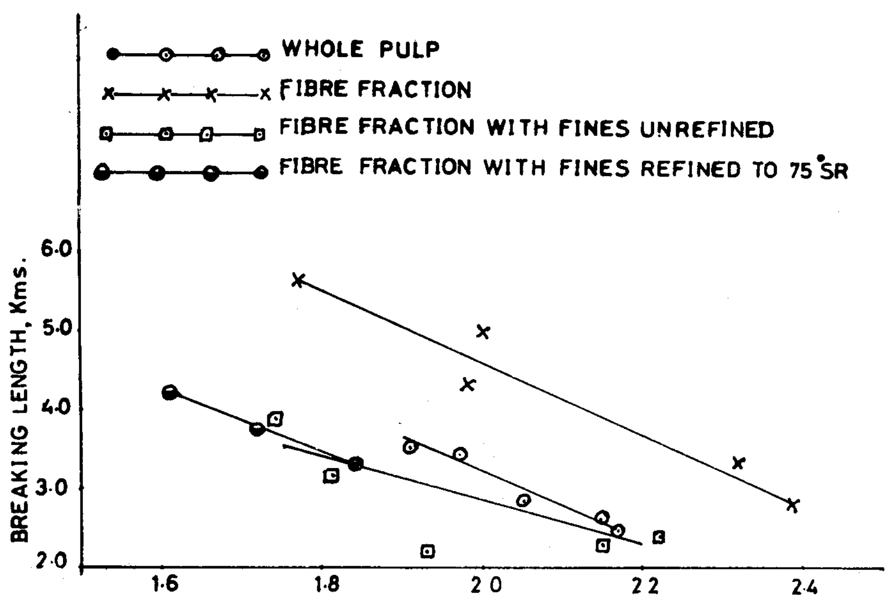

FIGURE 9 BULK VS. BREAKING LENGTH

The pulp evaluations carried out using Valley beater showed the same trend of increase in strength properties as in the case of disc refiner. However, the strength properties were higher than that of the disc refined pulps. The results are tabulated in Table V.

EFFECT OF FINES ON DIFFERENT PROPORTIONS

Four experiments were carried out. In each case varying amounts of fines was added to the fibre fraction with a 35 °SR slowness. Fines amount varied were 0, 12.5, 25.0 and 50.0 per cent. The results show a sharp decrease in breaking length, tear factor and burst factor when the fines were increased from 0 to 12.5 per cent. Then also the properties decrease though gradually, as the per cent of fines was increased. Bulk shows a decrease only between 0 and 12.5 per cent fines but otherwise remains rathehr constant in all other cases. The results are given in table V and shown in Fig. No. 13.

Set II : Effect of refining on fibre and and fines fraction :

The results given in table IV show that as indicated by the slowness of the pulp in °SR with one pass at different clearances, only the fines fraction get more refining where as fibre fraction do not get any or very little compared to fines fraction. This observation indicates that for paper of high strength fibre and fines fraction should be refined separately and blended together if desired.

Set III Effect of additive :

It is observed that generally all properties were increased when daicol (guar gum) was added. But the percentage increase in the properties differ according to the type of pulp used. In 'a' breaking length has increased from 2.27 to 2.51 km. i.e. an increase of 10.57 per cent; in 'b' from 3.79 to 4.46 km; i.e. an increase of 17.44 per

TABLE V

STRENGTH PROPERTIES OF PULPS — EVALUATION BY VALLEY BEATER

Particulars	Whole pulp					Fibre fraction					Fibre fraction + fines unrefined					Fibre fraction + fines diff. %				Fibre + fines beaten to diff. beating period, minutes			
																0	12.5	25.0	50.0	0	20	40	60
Beating period mts.	10	25	35	45	55	10	25	35	45	55	—	—	—	—	—	—	—	—	—	—	—	—	—
Final °SR	37.0	60.0	70.0	76.0	80.0	13.0	21.0	32.0	57.0	70.0	17.0	48.0	63.5	69.5	71.5	—	—	—	—	45.0	58.0	67.5	—
Drainage time sec.	8.5	10.5	14.8	38.4	91.4	9.6	9.4	12.1	20.3	49.6	8.6	10.2	13.0	24.6	46.1	—	—	—	—	—	—	—	—
Basis wt. g/m^2	56.2	58.1	57.4	58.4	58.5	58.9	61.0	60.4	59.2	62.4	62.4	60.5	65.6	62.3	61.4	61.0	59.3	65.6	60.3	64.5	57.7	61.3	59.3
Bulk, cc/g.	2.28	2.05	1.66	1.50	1.48	2.20	2.02	1.98	1.85	1.73	2.33	1.96	1.87	1.80	1.71	1.98	1.89	1.87	1.83	1.64	1.66	1.66	1.62
Breaking length km.	3.40	4.56	5.59	5.88	6.19	3.41	3.85	5.82	6.43	7.06	3.05	3.52	4.77	5.09	5.00	5.82	4.85	4.77	4.03	4.65	5.28	5.68	5.65
Tear factor	146.8	117.0	119.4	94.2	98.6	193.6	175.2	179.6	168.2	148.6	125.6	122.4	115.8	120.3	115.5	179.6	117.0	115.8	97.9	136.4	115.2	115.1	112.2
Burst factor	18.0	32.0	38.7	41.8	43.7	18.2	31.2	43.9	49.7	53.0	16.2	30.3	29.6	34.2	37.0	43.9	31.2	29.6	23.4	34.9	39.3	40.6	43.4
Double folds	25	189	552	628	541	51	691	1012	1252	1245	20	195	211	280	283	1012	188	211	65	578	351	464	364
Strength Index No.	1546	2043	2331	2225	2275	2137	2495	2872	2959	2900	1383	2040	2005	2143	2189	2872	2025	2005	1607	2360	2288	2318	2319

TABLE VI

EFFECT OF DAICOL ON STRENGTH PROPERTIES OF PULPS

Particulars	Whole Pulp			Fibre fraction			Fibre fraction + fines unrefined			Fibre fraction + fines refined		
	Rosin + Alum	Rosin + Daicol + Alum	% increase	Rosin + Alum	Rosin + Daicol + Alum	% increase	Rosin + Alum	Rosin + Daicol + Alum	% increase	Rosin + Alum	Rosin + Daicol + Alum	% increase
Slowness, °SR	18.0	18.0	—	21.0	21.0	—	37.5	37.5	—	66.0	64.0	—
							22.0	26.0		54.0	54.0	
Drainage time, scds.	9.5	10.1	—	9.5	9.7	—	10.0	10.3	—	11.7	12.7	—
Basis weight, g/m^2	61.8	62.1	—	57.0	55.4	—	57.3	58.2	—	58.5	59.6	—
Bulk, cc/g.	2.33	2.18	−6.44	2.13	2.07	−2.82	1.97	1.95	−1.01	1.89	1.81	−4.23
Breaking length, km.	2.27	2.51	+10.57	3.79	4.46	+17.44	3.77	3.98	+5.57	4.10	4.61	+12.44
Tear factor	127.1	139.3	+9.60	225.3	231.9	+2.93	150.0	148.7	+0.87	143.6	140.0	−2.57
Burst factor	12.8	14.8	+15.63	26.0	32.1	+23.46	24.8	27.7	+11.69	26.0	30.5	+17.31
Double folds	8	14	+75.01	157	510	+224.9	54	79	+46.29	216	240	+11.11
Strength Index, No.	1136	1332	+17.26	2342	2723	+16.27	1861	1986	+6.71	2058	2154	+4.77

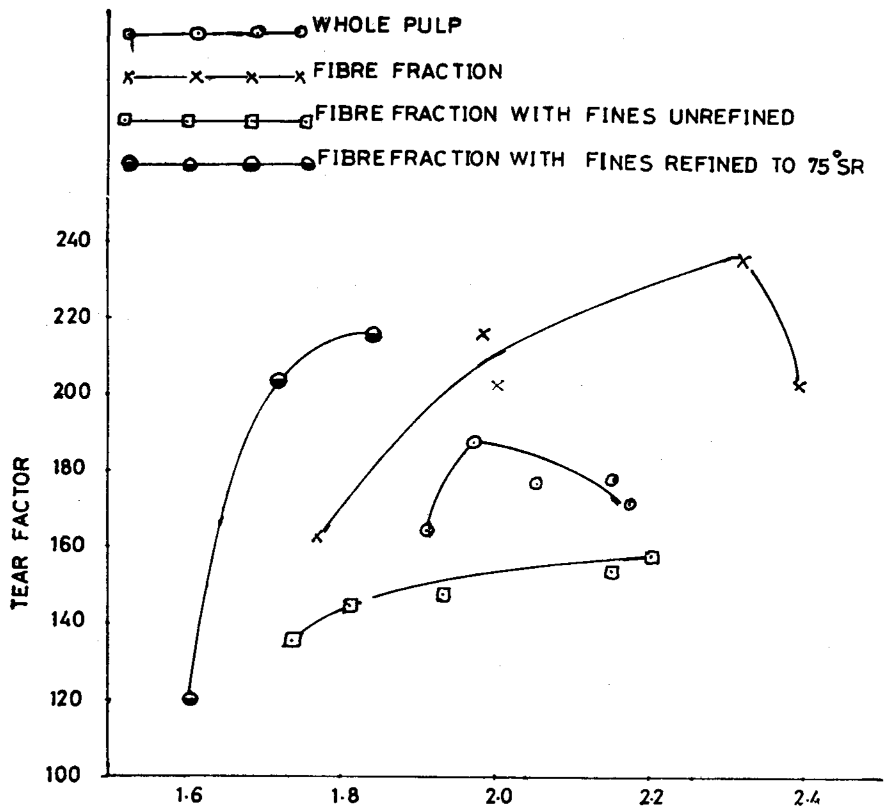

FIGURE 10 BULK VS. TEAR FACTOR

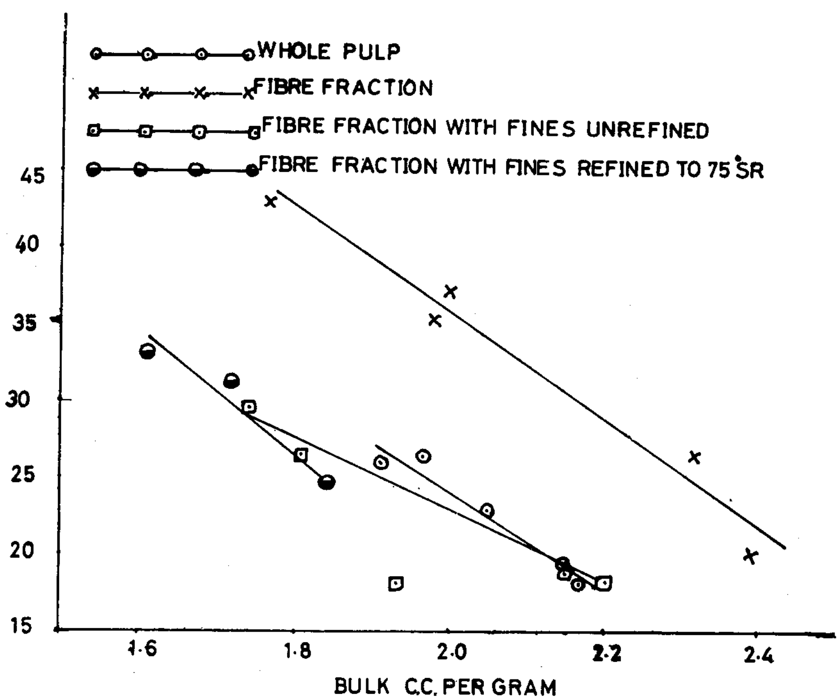

FIGURE 11 BULK VS. BURST FACTOR

cent; in 'c' from 3.77 to 3.98 km i.e. an increase of 5.57 per cent and in 'd' from 4.10 to 4.61 km. i.e. an increase of 12.44 per cent.

Tear factor has increased by 9.6 per cent in 'a'; by 2.93 per cent in 'b'; by —0.87 per cent in 'c' and by —2.51 per cent in 'd'.

Burst factor has increased by 15.63 per cent in 'a'; by 23.46 per cent in 'b'; by 11.69 per cent in 'c' and by 17.31 per cent in 'd'.

Folding endurance has increased by 75 per cent in 'a'; by 225 per cent in 'b'; by 46.6 per cent in 'c' and by 11 per cent in 'd'.

Strength Index: Strength Index has increased by 17.26 per cent in 'a'; by 16.27 per cent in 'b'; by 6.71 per cent in 'c' and by 4.77 per cent in 'd'. The results are shown in Table VI.

The results indicate that guar gum (daicol) gives better strength improvement when used with long fibres withou any fines. Next to this gaur gum (daicol) gives better strength improvements when used with fibre fraction and fines refined separately and blended.

CONCLUSIONS:

1. Bamboo is a heterogenous material consisting 60 to 70 per cent of fibres and 40 to 30 per cent fines chiefly consisting of parenchyma cells.
2. The fibre fraction gave considerably high overall strength properties to that of whole pulp.
3. Addition of unrefined and refined fines to the refined fibre fraction did not give stronger pulps than the whole pulp.
4. When high strengths are required as in the case of sack paper, etc. it is apparent that fines should be removed completely. The fines so removed could be used for mixing with the pulp where low or medium strength papers are required. Since the cost of these fines which constitutes 30 to 40 per cent of the bamboo pulp is quite high, it could not be discarded.

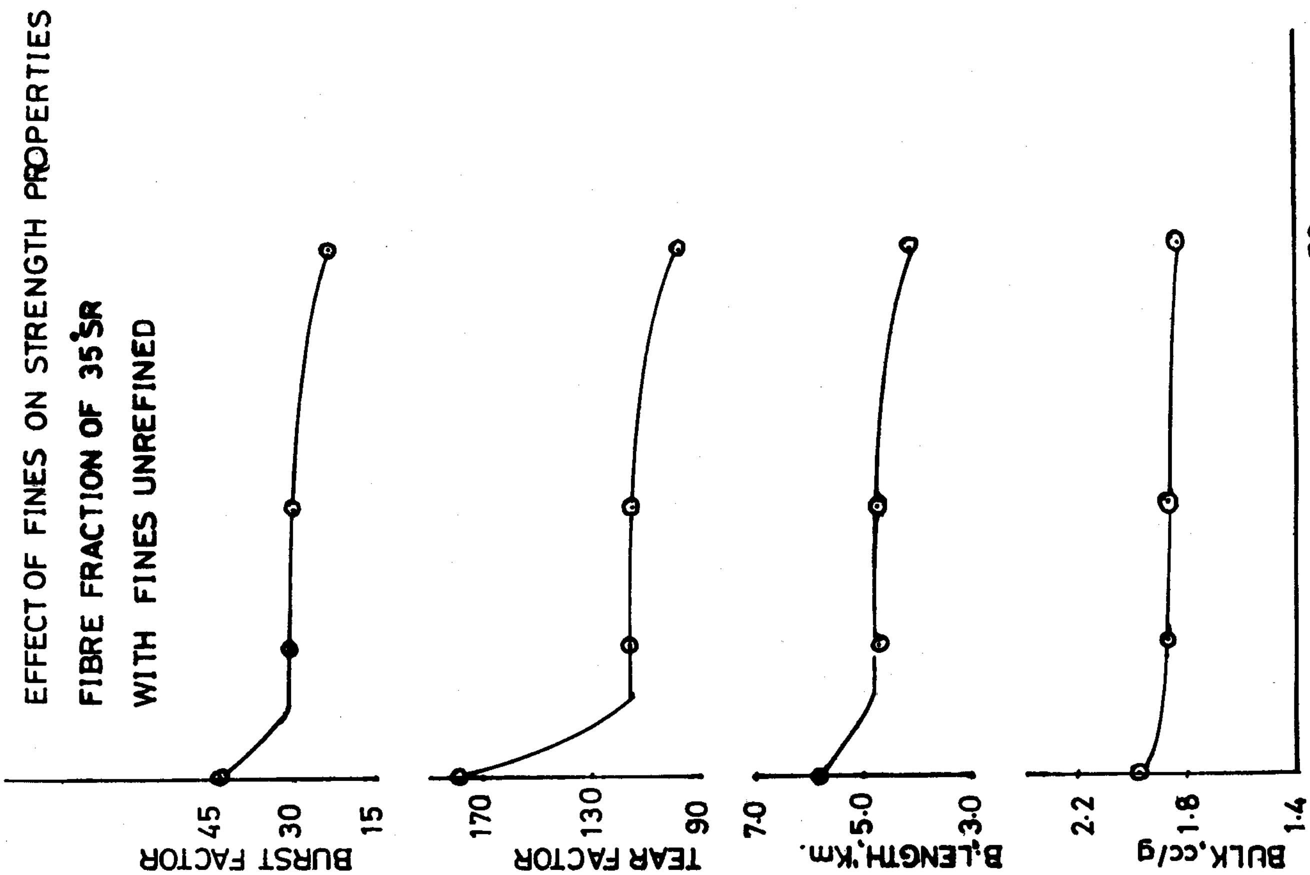

FIGURE 13 FINES PER CENT VS STRENGTH PROPERTIES

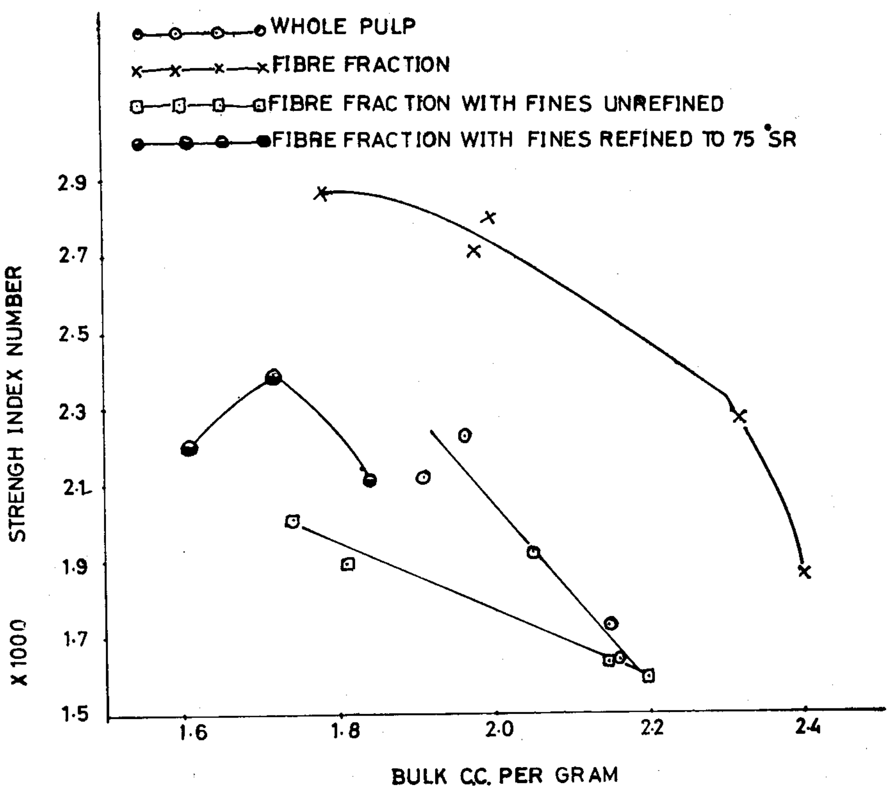

FIGURE 12 BULK VS. STRENGTH INDEX

5. Addition of guar gum (daicol) improves the overall strength properties of the pulps. However, the maximum strength improvement was observed when it was added to fibre fraction which can be used for high strength papers.

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