Surface Property Inter-Relationship in Wood-Fibre Paper

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Hardwoods are well recognised source of cellulose fibres for paper manufacture, because their chemical pulp give unique combination of properties, i.e. good sheet formation, high bulk, high opacity, medium tensile and good tear. They find application in all three types of papers-fine paper, newsprint including cheap grade printing papers and packaging materials.

However, from printability point of view, an understanding of the relationship between density, structure of hardwoods and paper surface characteristics and other properties is of great economic interest; because a wide variation is encountered in density, and fibre/vessel characteristics of hardwoods. In hardwoods, fibres are long and narrow, the length being 25 to 50 times the outer diameter or width. Vessel elements are generally shorter than fibres but many times wider. The characteristics of both fibres and vessels not only vary from species to species and tree to tree but also vary within tree. These differences are usually assessed in terms of age or tree size; which in turn is influenced by forestry factors, such as rate of growth, response to soil, climate, biological attacks etc. These differences and variations in density and structure of hardwoods exhibit their influence on paper surface characteristics and other properties and in turn the printability.

It is the gross difference between the size of vessels and the fibres that contributes to the problems associated with the printing of papers that contain hardwood pulp in their furnish. The main problem is the picking of these vessels from the surface of paper during off-set lithographic printing.

Printability is not a single property of paper. Instead, it is a broad, general term referring to all the properties of paper that contribute to printed matter of good quality. Printability can be judged from the results of individual properties of paper such as gloss, smoothness and ink receptivity. Probably the most important aspect of paper or paper board affecting printability is how well its surface attains full contact with the ink film or image being applied to it. The property of primary importance is smoothness that permits full contact of the surface of the paper with the inked surface of the plate or blanket. Smoothness under pressure is important. Instead, it is really the smoothening out of the surface and improved contact with the pressing surface that is important. Thus conformability is more appropriate in respect of printability.

Smoothness, vessel picking tendency and lateral conformability occupy central position in relating wood and paper properties; on the wood side through the Runkel ratio, fibre shape factor, fibre/vessel ratio and on the paper side through the surface roughness and degree of fibre collapse and relative bonded area.

The influence on collapse on beating, pulp yield, cell wall thickness, pulping process and drying have been studied by Page (1967), a direct studies of relationship between cell wall thickness and paper properties have been made by Dadswell and Watson (1962) and accounts have been given by Turner et al (1970 & 1971), of the effect of wood density on the properties of Eucalyptus cold soda pulp. Effects of drying on lateral conformability, have been studied by Mckenze and Higgins (1963 & 64). The load deformation curves of individual fibres in lateral compression has been determined by Harrington (1970). Heartler and Nyren (1970) have investigated the influence of pulp yield, cooling processes and mechanical process on collapsability on the fibre. Lucas (1970) has studied the stress-strain curves of fibre models on lateral compression and had observed a linear relationship between collapsing force and shape factor related to the ratio of lumen to fibre diameter.

From these studies the quantitative definition of the lateral conformability of a fibre can be derived as the reciprocal of the load required for the collapse.

In relating collapse to relative bonded area the proportion of inter fibre bonds in which at least one of the fibre partners is sufficiently conformable to permit maximum hydrogen bonding over the potential area of contact may be significant. This concept is relevant in considering the properties of paper made from pulps having a distribution of lateral conformabilities, for example, blends of thick and thin wall fibres or even pulps with a

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normal distribution of fibre dimensions.

The present paper described the results of the series of investigations designed to provide the data on the effect of structure of hardwood on paper surface characteristics and other properties.

RESULTS AND DISCUSSIONS

Density and fibre/vessel characteristics

Tables 1 to 3 give, the data on basic density and fibre/vessel characteristics of tropical hardwoods, eucalyptus of different age group and su-babul (Leucaena leucocephala) of different locality. The data on basic density, fibre-vessel characteristics indicate that a wide variation exists between species, and fibre/vessel characteristics also varied with locality and from tree to tree.

Tropical hardwoods

The mean fibre length varied from 877 µm (Diospyros melanoxylan) to 1151 µm (Anogeissus latifolia)., the mean fibre diameter varied from 13.57 µm (Anogeissus latifolia) to 46.44 µm (Boswellia serrata). It could also be seen from the data that fibre shape factor and the Runkel ratio was higher for species having higher density. So, in general there existed a direct relationship between wood density and the Runkel ratio and fibre shape factor.

The average vessel length varied from 270.0 µm (Acacia catechu) to 492.0 µm (Cleistanthus collinus) and average vessel diameter varied from 122.5 µm (Anogeissus latifolia) to 155.4 µm (Cleistanthus collinus and Diospyros melanoxylon) (Table-1).

Su-babul (L. leucocephala)

A perusal of data on fibre-vessel characteristics of L. leucocephala revealed that there is not much variation in fibre diameter, (23.33 - 24.17 µm), vessel length (333.10 -382.37 µm) and wall thickness of the three samples of L. leucocephala. Whereas appreciable variation in lumen diameter, fibre length and vessel diamter is encountered.

Further, the data on proportion of tissue indicated that the percentage of fibre varied appreciably with locality ranging from 58 per cent of Rajabhatkhawa plantation to 64.5 per cent for Pune plantation. The percentage vessels did not vary to any appreciable extent (9-10 per cent). The perenchyma cel percentage varied from 9 for Pune plantation to 17 for Siliguri.

The data in Table-1 showed that Runkel ratio in Rajabhatkhawa plantation was lowest (0.59) and it was highest in case of Pune plantation. The shape factor was also lowest in Rajabhatkhawa plantation (0.435) and highest in Pune plantation (0.532).

Eucalyptus

Effect of age: In case of Eucalyptus species, E. tereticornis have lower fibre length, fibre diameter and lumen diameter as compared to E. grandis. With in species there was no significant effect of age on these characteristics in either case as it is evident from the data recorded in Table-1. It will be further seen from the Table-1 that wall thickness did not vary appreciably either with species or with age. The value of the Runkel ratio and shape factor for E. grandis were lower than those found for E. tereticornis. In case of

Table-1
DENSITY AND FIBRE/VESSEL CHARACTERISTICS OF TROPICAL HARDWOODS (SINGH ET.AL. 1984, 1985)

Sl. No. Species	Basic density g/Cm³	Vessel diameter um	Vessel length µm	Vessel frequency per mm²	Fibre length µm	Fibre diameter (d) µm	Lumen diamenter µm	Wall thickness (2W)µm	Runkel ratio (2W/1)	Shape factor $\frac{d^2-l^2}{d^2+l^2}$
1. Acacia cetechu	0.975	145.8	270.0	17	913	14.8	5.85	4.49	0.7675	0.7297
2. Anogeissus latifolia	0.773	122.5	316.8	27	1151	13.57	3.69	4.94	1.338	0.8622
3. Boswellia serrata	0.394	162.9	367.8	33	935	36.44	28.85	3.79	0.1313	0.2294
4. Cleistanthus collinus	0.659	155.4	492.0	121	1130	26.62	12.80	6.90	0.539	0.6244
5. Diospyros melanoxylon	0.659	155.4	368.0	29	877	15.00	6.99	4.05	0.5793	0.6431
6. Pteroocarpus marasupium	0.734	150.5	303.7	13	895	17.45	9.675	3.89	0.402	0.5297
7. Yylia xylocarpa	0.766	142.6	311.4	21	1014	18.61	9.50	2.17	0.2284	0.5865
8. L.Leucocephala of locality										
(a) Pune	0.501	157.39	377.57	-	963.56	23.33	12.90	10.45	0.81	0.532
(b) Siliguri	0.476	163.94	33.10	-	1018.06	24.76	14.33	10.41	0.72	0.498
(c) Rajabhatkhawa	0.469	173.53	382.37	-	982.31	24.17	15.16	9.01	0.59	0.435

9. E. grandis (14-15 yrs)	0.390	193.20	549.33	6	969.00	20.63	13.93	6.70	0.4806	0.5439
10. E. grandis (18-19 yrs)	0.378	201.08	164.86	7	991	21.07	14.83	6.24	0.4211	0.3376
11. E. tereticornis (5-6 yrs)	0.580	145.4	368.47	10	735	14.22	7.63	6.59	0.8630	0.5526
12. E.tereticornis (14-15 yrs)	0.530	158.8	377.06	9	728	12.95	5.09	7.87	1.5466	0.7328

E. tereticornis these values increased with age, whereas in case of E. grandis and E. tereticornis the variation in vessel frequency was in a narrow range (6-10/mm^2). There was no variation in vessel frequency with age in either case. Bo.h vessel diameter and the vessel length were lower in ca^e of E. tereticornis as compared to E. grandis. These values also did not change appreciably with age in either case.

Effect of tree variation/locality: It would be seen from data in Table-2 and 3 that there was no appreciable variation in the Runkel ratio and fibre shape factor from tree to tree of same species grown in one particular locality but significant variation was observed in the Runkel ratio and fibre shape factor of E. tereticornis tree grown in four different localities (Viz. Bangalore, Coimbatore, Dehra Dun and Shahdol).

Effect of locality (composite sample of ten trees): Fibre vessel characteristics (Table -2 and 3) revealed that the value of the Runkel ratio, fibre shape factor, vessel length and vessel diameter varied from 1.41 - 1.98, from 0.708 - 0.797, from 268 -290 μm and from 152 - 169 μm respectively. There was no difference in fibre-vessel characteristics of Bangalore and Shahdol locality. But there was a significant difference in fibre-vessel characteristics of Coimbatore, Dehra Dun and Bangalore / Shahdol localities.

Paper surface characteristics and other properties

The paper surface characteristics and other properties of standard hand sheets in respect of bleached kraft pulps prepared from tropical hardwoods, eucalyptus of different age groups and locality and leucaena leucocephala of different locality recorded in Table-4 to 6.

Wood properties Vs paper surface and other properties: It has been found that wood density is highly related to collapsibility/conformability of the fibre. Fibre of high density are cylinderical and rigid, whereas those of low density woods are ribbon-like and flexible. The fibre characteristics could be collectively represented by lumen diameter, 2 W/l, and shape factor (d^2-l^2/d^2+l^2); where 2W is wall thickness, l is lumen diameter and d is fibre diameter.

It has been observed that both the Runkel ratio and fibre shape factor increased with basic density. Thus it will be seen that the Runkel ratio, fibre shape factor and basic density are inter-related.

In case of tropical hardwoods, as well as for E. tereticornis and E. grandis of different age groups the paper surface roughness was found to increase with increase in density, the Runkel ratio or fibre shape factor. However, there were clear-cut indications that the extent of increase in

Table-2

EFFECT OF TREE VARIATION OF FIBRE/VESSEL CHARACTERISTICS OF E. TERETICORNIS OF DEHRA DUN AND SHAHDOL LOCALITY

Tree No.	Runkel ratio (2W/l)	Shape Factor (d^2-l^2) / (d^2+l^2)	Fibre/vessel ratio
	Dehra Dun		
1.	2.03	0.80	4.75
2.	1.28	0.68	4.72
3.	1.00	0.60	6.07
4.	1.63	0.74	5.42
5.	2.19	0.82	5.13
6.	1.62	0.75	5.00
7.	1.31	0.68	6.17
8.	1.79	0.77	5.10
9.	1.65	0.75	3.88
10.	2.07	0.81	4.86

Composite of ten trees	1.41	0.708	4.70
		Shahdol	
1.	2.27	0.83	3.63
2.	1.95	0.79	4.94
3.	1.37	0.70	5.40
4.	2.19	0.82	4.73
5.	1.35	0.69	5.30
6.	1.94	0.79	3.93
7.	2.31	0.85	4.87
8.	1.25	0.67	4.98
9.	1.21	0.66	5.14
10.	2.09	0.81	4.37
Composite of ten trees	1.47	0.719	3.77

Table-3

EFFECT OF TREE VARIATION ON FIBRE/VESSEL CHARACTERISTICS OF EUCALYPTUS TERETICORNIS OF BANGALORE AND COIMBATORE LOCALITY (SINGH et . al. 1986)

Tree No.	Runkel ratio (2W/l)	Shape Factor $(d^2-l^2) / (d^2+l^2)$	Fibre/vessel ratio
		Bangalore	
1.	1.51	0.727	2.76
2.	1.51	0.726	4.66
3.	1.75	0.766	2.87
4.	1.69	0.758	3.06
5.	1.89	0.791	3.64
6.	1.91	0.777	4.01
7.	1.71	0.727	4.53
8.	1.76	0.759	4.75
9.	1.79	0.772	2.78
10.	1.58	0.733	2.94
Composite of ten tree	1.46	0.717	2.75
		Coimbatore	
1.	0.937	0.579	3.58
2.	1.67	0.768	2.88
3.	1.53	0.730	3.09
4.	1.63	0.746	2.86
5.	1.43	0.708	3.38
6.	1.68	0.756	4.66
7.	1.73	0.763	4.12
8.	1.47	0.715	3.59
9.	1.53	0.730	3.12
10.	1.47	0.719	4.38
Composite of ten trees	1.98	0.797	2.72

surface roughness with the Runkel ratio or fibre shape factor did not follow straight line relationship. Instead a number of patterns of increase in surface roughness with the Runkel ratio/fibre shape factor were observed (Fig. 1 and 2).

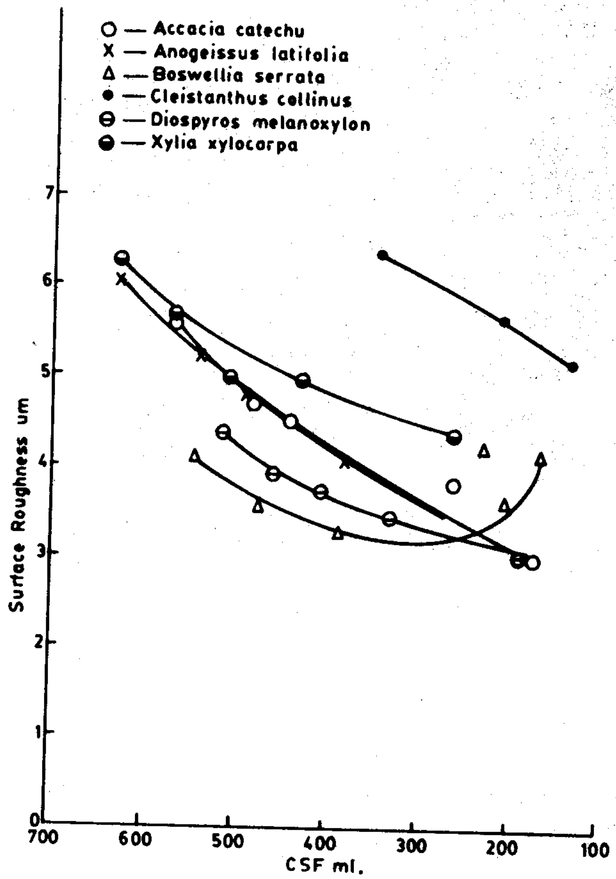

Fig. 1 — SURFACE ROUGHNESS OF BLEACHED KRAFT PULPS OF TROPICAL HARD WOODS

The influence of wood characteristics on printing properties of bleached kraft pulps of L. leucocephala of different locality was examined by measuring surface roughness and vessel pick number (Table-4). It has been observed that in the density range of 0.469 to 0.501 g/cm^3 there is little influence of the density on the Runkel ratio, fibre shape factor on surface roughness and vessel pick number of paper.

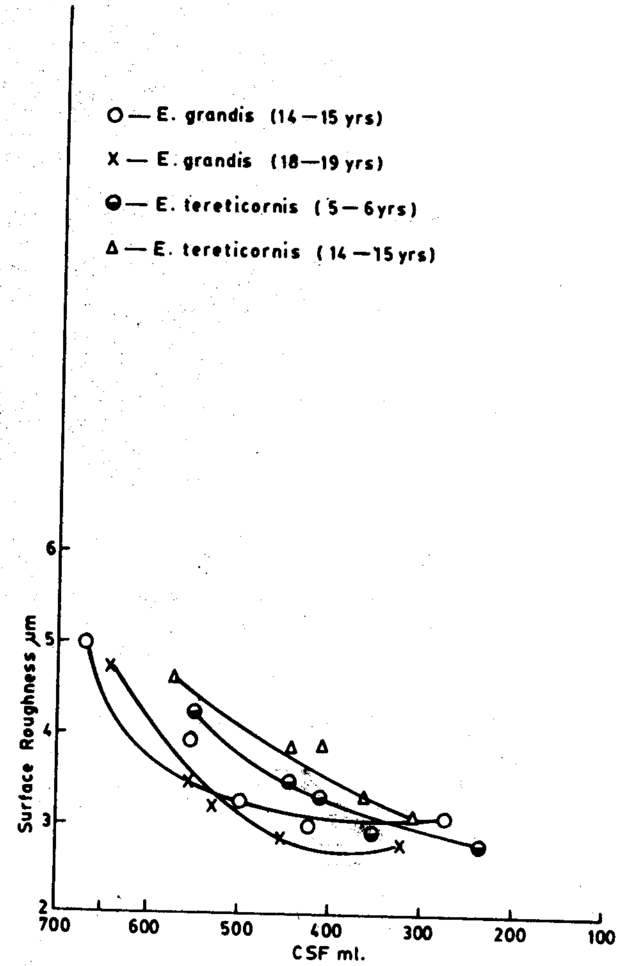

Fig. 2 — SURFACE ROUGHNESS OF BLEACHED KRAFT PULPS OF EUCALYPTS

In general, it was observed that most of the species yielded bleached kraft pulps having a surface roughness in the range of 3.00 to 4.00 u for standard hand sheets made

Table-4

FIBRE AND PRINTING PROPERTIES OF STANDARD HANDSHEETS OF BLEACHED KRAFT PULPS OF L. LEUCOCEPHALA AT 250 ML CSF (SINGH et. al. 1985)

Sample locality	Runkel ratio (2W/l)	Shape Factor $(d^2-l^2) / (d^2+l^2)$	Surface roughness μm	Vessel Pick number	Tensile index Nm/g
Pune	0.81	0.532	3.05	3.0	68.0
Siliguri	0.72	0.498	3.65	3.0	75.5
Rajabhatkhawa	0.59	0.435	3.65	3.0	83.5

d = Fibre diameter, l = lumen diameter
2W = wall thickness

from beaten pulp (250 ml CSF) (Table - 5 & 6). On the other hand vessel pick number, particularly in eucalyptus varied from tree to tree, with age and with locality and no definite relationship was observed between fibre/vessel ratio and vessel pick number.

Experimental

The methods for determining the density and fibre vessel characteristics have been discussed elsewhere by Singh et al 1984 and 1985.

Table -5

SURFACE AND OTHER PROPERTIES OF PULP AND PAPER FROM E. TERETICORNIS OF DIFFERENT LOCALITIES (BHANDARI et.al. 1988)

S.I. No	Property	Locality			
		Bangalore	Coimbatore	Dehra Dun	Shahdol
1.	Screened pulp yield, %	42.56	46.70	43.28	43.12
2.	Kappa number	26.71	28.65	23.46	23.04
3.	Bleached pulp yield, %	40.72	44.36	40.00	42.03
4.	Brightness (ISO), %	74.10	73.30	77.90	79.50
5.	Apparent density, g/cm^3	0.68	0.70	0.72	0.74
6.	Tensile indiex, Nm/g	62.96	73.26	67.69	73.39
7.	Tear index, mNm^2/g	9.17	9.16	8.99	8.78
8.	Burst index, KPam^2/g	4.98	5.19	5.07	5.58
9.	Surface roughness, um	3.61	3.61	3.63	3.17
10.	Vessel pick number	19	20	20	10
11.	Initial freeness, CSF, Ml	590	565	565	540
12.	Freeness at 4000 PFI Rev., CSF, ml	295	285	315	255

Table -6

EFFECT OF TREE VARIATION ON PAPER SURFACE PROPERTIES OF E.TERETICORNIS OF DIFFERENT LOCALITY (SINGH et.al. 1986)

Sl. No.	Property	Locality	Tree No.									
			1	2	3	4	5	6	7	8	9	10
1.	Surface roughness (u)	Bangalore	3.75	3.65	3.90	4.25	3.90	4.25	3.60	3.40	3.40	3.65
		Coimbatore	3.0	3.70	3.50	4.50	4.15	3.65	3.65	3.80	3.75	3.45
		Shahdol	3.92	3.97	3.32	3.83	4.26	3.19	3.55	3.03	3.50	3.81
		Dehra Dun	3.67	3.26	2.57	2.73	3.13	3.31	2.41	3.18	2.80	3.19
2.	Vessel Pick number	Bangalore	14	23	15	9	22	29	17	6	9	13
		Coimbatore	31	32	40	59	60	17	25	26	20	40
		Shahdol	15	34	10	20	31	44	18	6	23	20
		Dehra Dun	8	4	7	14	14	4	5	13	2	2

The experimental details for the determination of paper surface characteristics and other properties of pulps were also described elsewhere by Singh et al 1985 and Bhandari et al, 1988.

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