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Bibliography
Resource structure properties of natural cellulosic fibres – an annotated bibliography

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We present a review of the work on the structure and properties of some natural lignocellulosic fibres with a classified list of references on resource, structure, physico-mechanical properties and on the uses of these fibres. This list of references includes papers published in scientific journals and in the proceedings of conferences.

1. Introduction

In view of the energy crisis, the need to use renewable resources and the health hazards associated with the use of fibres like asbestos, glass and carbon, increasing attention should be paid to natural fibres. Increasing activity is anticipated in understanding the relationship between structure and properties of natural fibres and in synthesizing polymer, clay and cement matrix composites using natural fibres. It is likely that with increasing scientific inputs, several of these natural fibres could become as important as cotton and jute. It is anticipated that the present bibliography will accelerate scientific research on natural fibres.

Understanding of structure and properties of natural fibres can lead to a large number of applications for these fibres. A classified list of important references on composition, structure, properties and use of natural fibres is compiled into this bibliography covering the period 1920 to 1985. This covers papers which appeared in various scientific journals and were published in the proceedings of conferences.

Long vegetable fibres are mainly cellulose and lignin, although a number of minor components, such as wax, pectin, inorganic salts, nitrogenous substances, colouring matter, etc., are found in them. The total carbohydrate material is usually designated as holocellulose. The hemicellulose is not homogeneous and generally comprises polysaccharides of relatively low molecular weight, i.e. hexoses such as galactose and mannose, and pentoses such as xylose and uronic acid. Despite considerable research, the exact nature of lignin has not been clearly revealed, although it is generally regarded as three-dimensional polycondensate of dehydrogenation products of hydroxy and methoxy cinnamyl alcohols. Evidence is available for the existence of ester-linkages between the carboxyl groups of uronic acid and hydroxyl groups of lignin. Lignin is usually characterized by its content of methoxyl, carboxyl, hydroxyl and carbonyl groups. In certain cases, a fraction of the lignin may be strongly linked with the cellulose.

In extracted long vegetable fibres, the content of cellulose varies from 81% in pineapple to about 43% in coir. Among the bast fibres, jute has the highest lignin content at about 14% and ramie the lowest at 0.6%. Coir, which is husk fibre, contains about 45% lignin.

Fibre from different sources, age and parts of the plant has different structure and hence different properties. Cultivation and extraction of sunhemp fibre is reported by Chaudhari (1945). Development of finishing net materials by sunhemp fibre is reported by Miyamoto and Shariff (1959). Increase in production of sunhemp, production of chemical pulp, modification of chemical constituents, characteristics, comparison of physico-mechanical properties with other fibres and utilization of sunhemp fibre have been reported by several other authors. Maiti (1967) studied the microscopic structure of sunhemp fibre. Chand *et al.* (1985) reported the complete structural details of sunhemp fibre and a comparison of properties with other plant-based fibres. The mechanical behaviour of sunhemp fibre and the mechanism of cell fracture at different testing speeds has been reported by Chand *et al.* (1986). Non-carcinogenic cement sheet using sunhemp fibre has been developed by Khazanchi *et al.* (1985). Polymer-based composite for the development of boards and partitions have been developed by Chand and Rohatgi (1986).

Sisal fibre is a hard fibre and is mainly used in making ropes. Nearly 4.5 million ton of sisal fibre is produced every year throughout the world. The main producing countries are Tanzania and Brazil. Sisal is extracted using a power decorticator. Mukharjee (1964) reported the hemicellulose of sisal fibre. Corson (1970) reported the use of sisal fibre in concrete, and Lambrinou (1970) used sisal fibre in the development of floor covering. Several other authors studied structural parameters, dyeing of sisal, fibre estimation of macromolecular parameters, and polymer deposition on sisal fibre. Complete structural studies, such as cell arrangement, tensile strength and possible future uses

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of sisal fibre, are reported by Chand and Rohatgi (1986). Bonding of sisal fibre with polyester has also been reported by Chand *et al.* Composites of sisal fibre, after improving the surface of fibre with polyester resin, have been developed and their performance has been evaluated by Chand *et al.* (1986).

Bamboo is mainly used for making huts in rural areas and for making baskets. The structure and hemicellulose of bamboo fibre were determined by Machawa (1976). Chemical composition of bamboo, utilization in reinforcement, pulping and paper making has been reported by several other authors.

Coir fibre is extracted from the husk of the coconut. World export of coir every year mainly from India and from Srilanka is about 200 000 ton. Coir fibre has been used for a variety of applications such as for making mats, carpets, ropes and brushes. Curled coir fibre is used in the manufacture of coir pads which are used for upholstery. Coir fibre is also used for preparing packing material and for thermal insulation.

Bandopadhyay and Roy (1965) studied the structure of coir fibre, and Rohatgi and his co-workers (1982) established the complete structure and properties of this fibre. They have developed the composites with polyester and have tried to improve the bonding of this fibre with polyester resin (1981–83).

Fibre from pineapple has been obtained by different methods such as retting and decorticating. The fibres are coarse, quite hard and brittle and obviously not fit for spinning. The fibre is mainly holocellulose; Palmario (1976) has extracted pineapple fibre using retting and decorticating processes. Ghosh and Sinha (1977) have tried to assess the textile value of this fibre after processing it on a jute machine. Sharma (1982) carried out work on the structure, properties and chemical composition of this fibre.

Ramie fibre is grown all over the world, the main producers being USA, Japan, China and India. Ramie fibre has some excellent characteristics, namely long fine cells, a low lignin content a high degree of crystallinity and orientation, and high tenacity. This fibre has been extensively used as a standard source of cellulose in the investigation of fine structure, but its commercial exploitation has so far received less attention than it appears to deserve. Apart from its specific growing conditions, one reason for limited exploitation is its high gum content and the difficulties associated with degumming. The usual method of degumming is chemical treatment which is costly and time consuming. Successful exploitation of a simpler degumming process would appear to enhance the possibility of the fibre's exploitation on a greater scale. Bose (1956) reported some physical properties of the fibre. Mazumdar (1972) processed this fibre on jute machinery. Roy and Das (1979) have reported the effect of alkali treatment on the morphology of this fibre.

Palm fibre is brown in colour. Chao *et al.* (1971) measured the fibre dimensions and Mayahi and Fofan (1973) developed composites of this fibre with methyl methacrylate. Chand *et al.* (1985) have measured the complete structural details of palm leaf fibre thermal degradation. They have reported some possible uses of this fibre.

Mesta fibre is similar to jute and much work on extraction blending with jute and chemical composition has been reported by Sarkar and Sen of JTRL (ICAR) India (1952).

Water hycinth (*Eichornia*) is available all over the world in lakes. It is fibrous and its fibre is brownish. Zerudo and Tadena (1979) have used this fibre in the development of pulp and board. Some other reports are also given on possible uses of this fibre (Ghosh *et al.* 1981).

Banana fibre is available in India and in many other parts of the world. Banana fibre is white, fine, soft and lustrous, and can be processed on jute machinery. It is a multicellular fibre. Span (1921) reported use of this fibre as rope. Biswas and Athwale reported the chemical composition of this fibre. Several other reports on chemical composition and its pulping characteristics

TABLE I Properties of natural fibres

Fibres	Width or diameter (μm)	Density (kg m^{-3})	Microfibrillar angle (θ)	Cellulose lignin content (%)	Tensile properties: Modulus (GN m^{-2})	Tensile properties: UTS (MN m^{-2})	Elongation (%)
Coir leaf sheath (thick fibre)	1100–1600	1190	30 ± 5	41.90/25.85	4.543	115.236	3.97
Coir leaf sheath (middle fibre)	300–1000	750	31 ± 4	41.90/29.05	3.585	91.965	6.227
Bark of the petiole	250–550	690	21 ± 1	46.03/12.09	15.094	185.52	2.06
Root	100–650	1150	30 ± 1	39.1/29.48	6.2	157	3
Coir	100–450	1150	39–49	43/45	4–6	131–175	15–40
Banana	80–250	1350	11	65/5	7.7–20.0	529–754	1.0–3
Sisal	50–300	1450	10–22	67/12	9.4–22	530–640	3–7
Pineapple	20–80	1440	14–8	81/12	34.5–82.5	413–1627	0–1.6
Jute	200		8.1	63/–	17.42	239.46	1.16
Mesta	200	1470	9.6		12.62	157.30	1.56
Kusha Grass	390	–	–	49.2–56.5 / 24.9	5.699	150.59	2.12
Sunhemp	48	–	9.8	–	2.685	148.5	0.84
Palm leaves stalk	240	–	–	–	2.221	98.14	30.8

*Source N. Chand, S. Sood, K. G. Satyanarayana, P. K. Rohatgi, *J. Sci. and Ind. Res.* **43** (1984) 489.

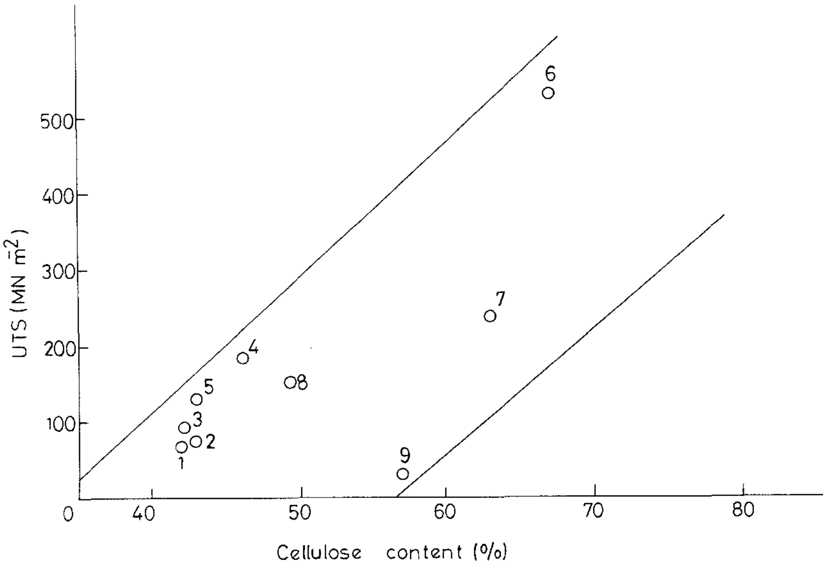

Figure 1 Dependence on ultimate tensile strength (UTS) on microfibril angle of ligno-cellulosic materials. *Source N. Chand, S. Sood, K. G. Satyanarayana and P. K. Rohatgi, JSIR 43 (1984), 489. 1, Spath of coir; 2, rachis of coir; 3, leaf sheath, coir; 4, bark of petiole, coir; 5, coir; 6, sisal; 7, jute; 8, kusha; 9, *Ipomea carnea*.

are reported by Barkley (1949). Rohatgi (1983) and his group have established the fracture mechanism of the cells of banana fibre at different speeds of testing. They found that the fibre is multicellular having a cell length of the order of 900 to 4000 μm and width 80 to 250 μm. The major chemical constituents are cellulose 63 to 64%, lignin 5%.

Sabai grass is available mainly in India and in Napal, in large quantities, Chaturvedi (1938) reported the cultivation and uses of this grass. This grass is fibrous and is used for making ropes. After chemical composition determination of this grass by Momin (1950), several other applications, such as in pulping and in printing paper, have also been suggested. Latif (1964) has converted this grass pulp into rayon. Physical properties of this grass fibre from different parts of the plant has also been studied Singh (1982).

Research and development work on jute fibre has mainly been done by the Indian Council of Agricultural Research (ICAR), India. Nodder *et al.* (1940) observed physical properties of jute fibre and established the technique of spinning yarn from small quantities of jute fibre. Nodder (1945–46) measured the strength of jute yarn and observed the effect of moisture and strength characteristics. Sarkar *et al.* (1948) estimated the hemicellulose and cellulose contents of jute fibre.

Chakraverthy (1935) reported the modulus of jute filaments. Chaudhari (1957) established the structure of hemicellulose obtained from jute fibre. Bandhopadhyay and Chatterjee blended jute fibre with mesta fibre, and Chakaravarthy (1967) correlated tensile properties with cell arrangement of the fibre.

Roy (1967–69) reported the crystallinity of this fibre. He observed that the degree of crystallinity changes with the moisture condition of the fibre. Paul (1973) observed a decrease in jute fibre strength on storage.

Winfield (1974) developed low-cost houses using jute–polyester composites and Debnath (1975) developed jute–viscose blends. Mazumdar and Roy (1977) reported the chemical constituents of jute ribbons. Excellent work was performed by Debnath (1978–79) on needle punching technique. Mazumdar *et al.* (1981) measured the strength characteristics of jute fibre and compared it with other natural fibres.

A number of studies have been done by JTRL (ICAR) India, the FAO, Tropical Product Institute, International Agricultural Research and by the Regional Research Laboratory (CSIR), India. However, this review provides a list of the work carried out on structure properties, utilization of these natural fibres, which are renewable in nature and can be utilized in a better way. Some abbreviations such as "(gp)" for general properties, "st" for structure, "fract" for fracture behaviour, and "ch" for chemistry and "aq" for effect of water, have been used in some references. Some physical properties are listed in Table I. Surface modification and some genetic manipulation for improving the strength of these fibres is required. Fig. 1 shows the dependence of tensile strength (UTS) on cellulose content and Fig. 2 shows the UTS dependence on microfibril angle of these

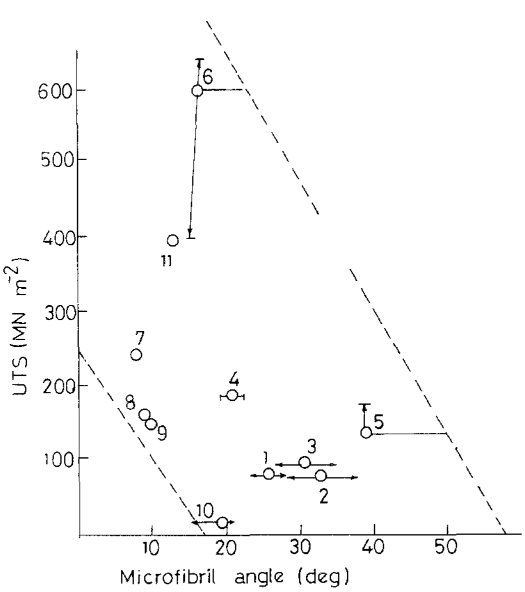

Figure 2 Dependence of ultimate tensile strength (UTS) on cellulose content of ligno-cellulosic materials. *Source N. Chand, S. Sood, K. G. Satyanarayana and P. K. Rohatgi, JSIR 43 (1984) 489. 1, Rachis of coir; 2, spath of coir; 3, leaf of coir; 4, bark of petiole, coir; 5, coir; 6, sisal; 7, jute; 8, mesta; 9, sunhemp; 10, *Ipomea carnea*; 11, banana.

natural fibres. These bands show that tensile strength of these vegetable fibres depends on the cellulose content and the microfibril angle of the fibre. In future after improving the strength characteristics and bonding capabilities and with higher moisture and fire resistance these natural fibres could be used in better ways in the development of rural housing elements, fancy decorative articles, boards, handicrafts and partition boards.

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