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Characterization of Bamboo, Cotton and Polyester fibres structure and properties

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Abstract

Textile industry is presently finding the alternative green fibres for providing healthy, comfortable, recyclable and biodegradable fibres. Majority of textile fibres are found in natural form such as seed fibres (cotton) or animal hair (wool). Some of the natural fibres are extracted from ligno-cellulosic fibrous plants such as flax, jute, hemp, kenaf, sisal, ramie, coir, and bamboo which are widely used not only for developing products, textile but also used in building materials, animal food, agrochemicals and as a source of bio-polymers and energy.

Bamboo has attracted renewed interest from an environment point of view. Bamboo needs no irrigation and fertilizers to grow and its unique rhizome system is responsible for its fast growth rate. Bamboo possesses an excellent carbon sequesting property makes it more useful. Bamboo fibres are new kind of regenerated fibres introduced in to the textile field due to some of their unique properties. Bamboo belongs to bast fibres produced from bamboo pulp similar to viscose rayon. Bamboo as a raw material is remarkably sustainable and versatile and the bamboo fibres are often labelled as, biodegradable, eco-friendly antibacterial, antimicrobial, good UV blocking properties etc., In this chapter a detailed review is presented on cotton, polyester, bamboo growth, geographical distribution, bamboo fibre manufacturing processes, yarn and fabric characterization for various textile applications.

In the present work bamboo, cotton and polyester fibres were chosen Characterization of bamboo , cotton and polyester fibres viz; crystalline structure, chemical structure, chemical composition, thermal characteristics and density using X-ray diffraction(XRD), Fourier transform infrared (FTIR), scanning electron microscope(SEM), thermo analyzer(DSC and TGA) and density was done by solvent

immersion method. X-ray results of bamboo, cotton and polyester fibre confirms that cotton fibre shows highest crystallinity of 67.43 % whereas bamboo shows lowest 35.48% and polyester 60.2%

Different absorption bands in the IR spectra are assigned from 4000 to 650 cm^{-1}. The absorption bands for bamboo and cotton fibres appeared around 3500-3200 cm^{-1} were due to hydroxyl O-H stretching vibration. This O-H stretching may be associated with absorbed alcohols found in cellulose, hemicelluloses, lignin, extractives and carboxylic acids. The FTIR analysis of polyester fibres confirms the presence of methyl groups.

From the SEM images it was observed that the longitudinal section of bamboo fibre is similar to the conventional viscose fibre. There were no nodes in the longitudinal surface of the bamboo fibre which is different from cotton and polyester. The surface of the fibre becomes rough and consists of many micro gaps which make the fibre more hygroscopic. The polyester fibre shows smooth surface with higher orientation. The cotton fibre surface was flat with a twisted ribbon like structure caused by spiralling of cellulose fibres. The presence of natural folds running parallel along the cotton fibre axis was observed. Polyester fibre show lowest density (1.38 g/cm^3) compared to cotton (1.53 g/cm^3) and bamboo fibre (1.51 g/cm^3). Thermal studies showed that all the fibres have different thermal stability and decomposition temperature. Polyester fibre show highest thermal stability temperature (431.78^0) and bamboo shows minimum thermal stability temperature ($333.74\ ^0$) and residue is maximum (15%) in polyester fibre and minimum in bamboo fibre (6%).

Key words: XRD,FTIR ,hemicelluloses, crystallinity ,lignin, thermal stability

Introduction

The usage of bamboo in china dates back to ancient times. In addition to making decorative items, musical articles and construction purpose it also offered people abundant resource for their daily life use [1]. All over the world the wide application of bamboo for various activates has been thought much by consumers.

Bamboo is a perennial plant belongs to grass family and it is a fastest growing plant and it is a rich renewable resource for developing many useful products. Bamboo is the world's most sustainable resource and abundantly available.

Bamboo comprises over 1500 species including 87 genera worldwide and its rhizome structure is responsible for its rapid growth. Bamboo grows naturally in all continents except Europe and not evenly distributed in humid, tropical, subtropical and temperate regions [2]. China is the largest producer of bamboo products in the world. India is the second largest country in the world next to china with high diversity of bamboo products. In India nearly 18 genera & 136 species are grown and cover about 8.96 million hectares of land including forest, homesteads and private plantations which accounts nearly half of the total bamboo cultivation in Asia.

Latest development in fibre research is the use of bamboo fibre in various textile products that was earlier used in construction materials, decorating items such as furniture and high performance composite materials for years together [3]. Bamboo is a rich renewable natural resource of cellulosic nature and it originates from the bamboo grass [4].

Bamboo regenerated cellulose fibres are used in the manufacturing of apparel, home furnishing, sanitary pads and medical applications such as mask, bandage cloth, surgical cloths and gowns [5]. The unique properties such as antibacterial, wearability, moisture absorption, ventilation, excellent comfort, quick drying etc, made the bamboo fabrics more attractive and useful in many textile applications.

There are two ways to produce bamboo fibre from bamboo plant. The mechanical means of producing bamboo fibre is crushing the woody parts of bamboo and treating with natural enzymes to break the bamboo walls into a softy mass and combed out mechanically and spun into yarn. Regenerated bamboo viscose fibres were produced in a wet spinning process in which natural cellulose (bamboo leaves, stems and inner pith) is used as a raw

material in a hydrolysis alkalization process [3]. Bamboo charcoal is produced using nanotechnology in which bamboo is dried and heated at 800^0 C until it turns into Nano particles. These Nano particles are embedded into cotton, polyester and nylon fibres.

Microbial growth is common on textiles under suitable conditions like availability of sufficient water, air and nutrients [5]. In such conditions many natural fibres are rapidly colonized by microorganism, bacteria and fungi are metabolized by them as a part of their food chain. Natural fibres are more susceptible to bio deterioration especially in hot humid conditions. Cloths such as under garments, sportswear, socks, health care textiles such as bedding, gowns, masks, towels and gauzes are best examples where microbial growth is rapid.

Bamboo fibers recently entered the market claiming that bamboo fabrics are eco-friendly and antibacterial [6]. The compound called bamboo **Kun** represent a hydroxyl functional group [-OH] is responsible for the antibacterial property in bamboo.

The inherent characteristics of bamboo fabrics made them suitable for health care, hygiene and comfort in the medical application of textiles. The various products made from bamboo viscose include disposable and non-disposable items such as surgical gowns, masks, diapers, gloves, napkins, and baby diapers etc, used in hospitals. Bamboo fibre products are natural antibacterial, with good moisture vapor transmission and quick drying property, non-allergic to skin, smooth, soft and can suitably used in many textile applications.

Bamboo is a new kind of regenerated fibre, is of great interest due to many advantages. Raw material for bamboo is easy to obtain and its cost is relatively low, since its abundant availability and fast growing nature. Utilization of bamboo fibre is more in countries like China and Japan due to its commercial exploitation and ease of avaibility. Although characteristics and application of bamboo fibre in various fields have been widely investigated but research on bamboo viscose fibre for textile applications is limited.

The structure of Bamboo fibre produced from Neosinocalamns affinis, was observed using FTIR, X-Ray, NMR & SEM [7]. The chemical composition, crystalline structure, molecular structure and morphology of bamboo viscose fibre were observed. According to the observations the chemical composition of bamboo fibre is cellulose, crystalline structure is cellulose-II, with a small molecular mass & low degree of polymerization. The bamboo cross section images showed that the fibre is round with

small lumen. It has high breaking strength, low elongation & good water absorption properties.

Based on the structural studies conducted on bamboo and other cellulosic fibres, in this chapter an attempt has been made to investigate structure and properties of bamboo, cotton and PET fibres. For this purpose three different fibres were chosen, i.e. one regenerated fibre (bamboo viscose), one natural fibre (cotton) and one synthetic fibre (polyester).

Fibre structural analysis such as, Fibre crystalline structure, chemical structure, chemical composition and density of all the fibres using X-ray diffraction (XRD), Fourier transform infrared (FTIR), scanning electron microscopy(SEM), thermal analysis (DSC and TGA) and density by solvent immersion method were carried out.

Materials & Methodology

Materials; Fibres chosen for the present work are

- Bamboo viscose fibre.
- Cotton fibre (Brahma variety) and
- Polyester fibre

Bamboo viscose fibre of length 35 mm and fineness of 1.80 was procured from Gokak mills Gokak Belagavi, Karanataka, India. Cotton fibres (Brahma variety) were procured from Anjaneya Cotton Mills Davangere, Karnataka India. Polyester fibre of length 35.5mm and fineness of 1.70 d was procured from Reliance Industries Patalaganga, Mumbai India. The bamboo viscose, cotton and polyester fibres used for the present study are shown in the **Fig.1 (a), (b), and (c)** respectively.

(a) (b) (c)

Fig. 1 (a) Bamboo viscose, (b) Cotton and (c) Polyester fibers

Methodology

Characterisation of Bamboo, Cotton and Polyester Fibres

Wide angle X- Ray Diffraction (WAXD)

The percentage crystallinity of bamboo, cotton and polyester fibre were determined using wide angle X-ray diffraction (XRD; $2\theta = 4 - 40^{\theta}$), using D/max B diffractometer spectroscopy D8-advanced – Bruker make USA.

Fibres were ground into fine powdered as a measuring sample. The scanning velocity was 5^0/min, the voltage was 40 Kv, and the electric current was 50mA. The rotational target was a Cu target which produces X-rays with a wavelength of 1.5418 A $^{\theta}$ counting was carried out at 20 steps per degree. The observed equatorial X-ray scattering date in the 2θ=10-35^0 range was corrected and resolved using a well established curve fitting procedure. The peak widths at half-height have been corrected using the stokė s deconvolution procedure. The apparent crystallite size of a given reflection was evaluated using the Scherrer equation;

$$L\ (_{hkl}) = \frac{k}{\beta}\lambda.\cos(\theta)$$

Where, θ = Braggs angle

λ = Wave length

β = integral breadth.

K = Scherrer parameter.

$L(_{hkl}$ = mean length of the crystallite perpendicular to the planes.

Crystallinity of fibre was calculated by finding the total area of I v/s 2θ curve and the area under the crystalline region of I v/s 2θ curve. Crystallinity (X %) was found out using the following equation.

$$x\% = \frac{Ac}{Ac+Aa} X\ 100$$

Ac = Area under crystallinity region

Aa = Area under amorphous region

FTIR

The infrared spectroscopy (IR) instrument provides the complete information about fibre structure considering the characteristic vibrational energy of the different chemical

groups present in the fibre molecule. The regenerated bamboo, cotton and polyester fibres were taken to study the fibre structure using Bruker Alpha FT-IR Germany which is working on Attenuated Total Reflectance **(ATR -A537)** was used for the present study. Frequency range used was 4000 cm^{-1} to 600 cm^{-1}.

Surface morphology (SEM)

The Scanning Electron Microscope (SEM) TESCAN VEGA 3LMU with a voltage setting of 5 kV and a specimen to detector distance ranging between 8 mm to 12 mm was used to investigate the longitudinal view of bamboo, cotton and polyester fibres. Before observation the samples were coated with gold for five minutes by ion sputtering.

Density

Density is the mass of unit volume and expressed in gms/c.c. The measurement of density depend on immersing the material in a liquid that displaces all the air around the fibre. The density of bamboo, cotton and polyester was determined using the method of immersing the fibre in the organic liquid. In this case benzene was used to determine the density of fibre sample. Ten readings were taken and the average was calculated using the formula,

$$\rho = \frac{M_f}{V_f}$$

Where ρ = density of fiber, Mf = mass of the fibre, V_f = volume of the fibre

Thermal analysis of fibres

Thermal analysis is conducted to understand the thermal stability, glass transitition, melting temperature and other properties as a function of temperature of polymers and fibres. Thermal characterization of bamboo, cotton and polyester fibres was carried out using and TGA. Thermo analyzer SDTQ600 -TGA instrument, was used for this purpose. The fibre sample of 3-4 mg was taken and evenly and loosely distributed on the sample pan. The fibre samples were subjected to raising temperature regime over the range of ambient to 800 ^{0}C at the heating rate of 10 ^{0}c/min. All the tests were conducted under dry and pure nitrogen atmosphere.TGA and derivative (DTG) traces were obtained for all the fibres.

Tensile properties of bamboo and polyester Fibre

***Strength and elongation**:*

The Fibre strength and elongation of bamboo, cotton and polyester fibres were measured using Eureka stelometer which works on CRL principle. Fibre strength and elongation were recorded to the nearest 0.01kg and 0.5% respectively. Fibre strength (gms/tex) and elongation (%) were calculated as per ASTMD1445-05 standards for all the fibres. Ten readings were taken and the average was calculated.

***Moisture content and moisture regain**.*

The moisture content and moisture regain of bamboo, cotton and polyester fibres were measured using Statex Moisture Tester. Approximately five gm sample was taken, thoroughly opened, cleaned and placed on the physical balance which is in the electric oven.. After 30 minutes weight was checked and decrease in weight was observed and this was repeated for every 10 minutes till a steady reading is obtained. With the help of these two values the moisture content and moisture regain were calculated The moisture content and moisture regain of all the fibres were calculated using the formula

Moisture content:-$W/D \times 100$

Moisture regain:$W/D \times 100$

Where W= weight of moisture present.

D = Dry weight of fibres.

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Results and discussions.

X- Ray Diffraction:

Table. 1 Crystallinity(x %) of fibres

FIBRE TYPE	Lattice plane	Inter planer distance(D_{nm})	Crystallinity(x%)
Bamboo	101 $1\bar{0}1$ 002	– 5.683 4.003	35.48
Cotton	101 $1\bar{0}1$ 002	5.902 5.368 3.897	67.3
Polyester	010 $1\bar{1}0$ 100	5.501 3.920 3.430	54

The X-ray diffraction patterns of the three fibres is shown in **Table 1** and shown in **Fig 1to 3.** Regenerated cellulose fibres with a cellulose II structure have peaks at 2^{θ} = 15-16^{0} and 21.8^{0} assigned to (101) and (102) reflection, respectively. From the figure it is observed that bamboo and cotton fibres have a cellulose II structure. The intensity of peak at 2^{θ} =21.8^{0} is much higher than that of 2^{θ} =15-16.The X-ray crystallinity of bamboo and cotton found to be 35.48 and 67.43% respectively.

The polyester fibre shows fully developed crystalline structure with relatively enhanced crystalline orientation as shown by the intensity, sharpness and equatorial and off-equatorial reflections. The equatorial trace shown in the figure can be resolved into three crystalline peaks viz.010, 110 and 100 planes as 5.5, 3.9 and 3.4 nm respectively. Crystallinity(X %) for polyester fibre found to be 54%.

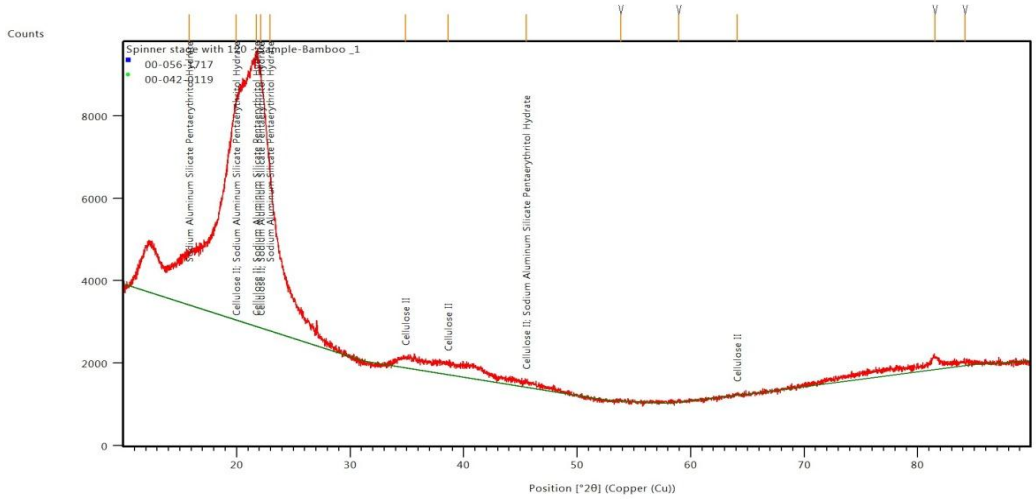


Fig 2 XRD graph of bamboo fibre

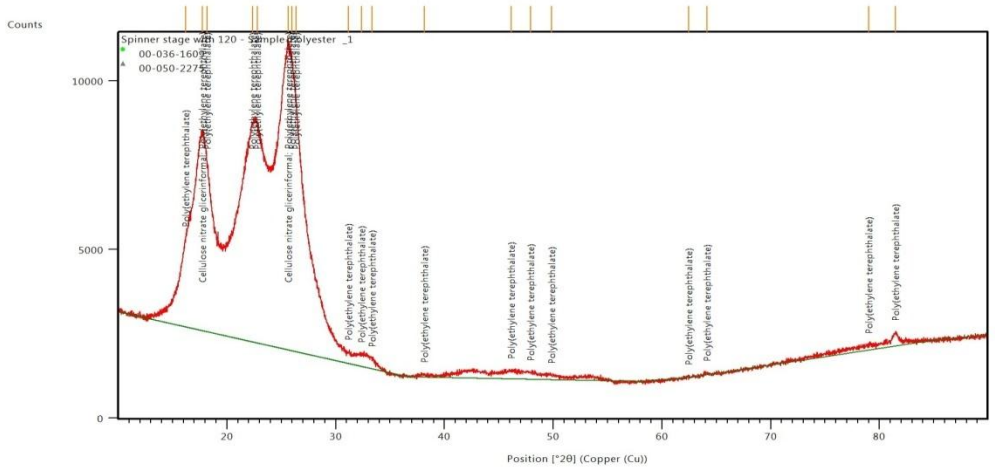


Fig 2 XRD Graph of cotton fibre.

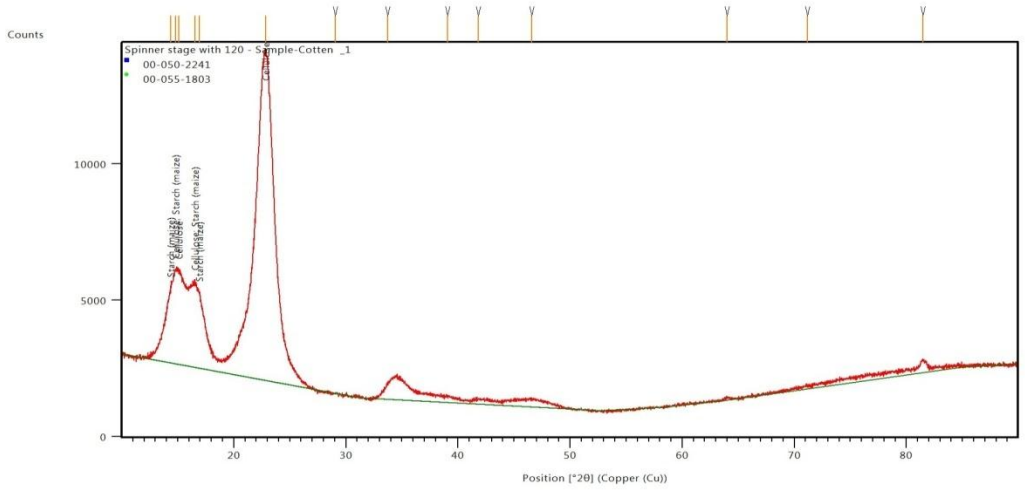


Fig 3 XRD Graph of polyester fibre.

Fourier Transform Infrared spectroscopy (FTIR)

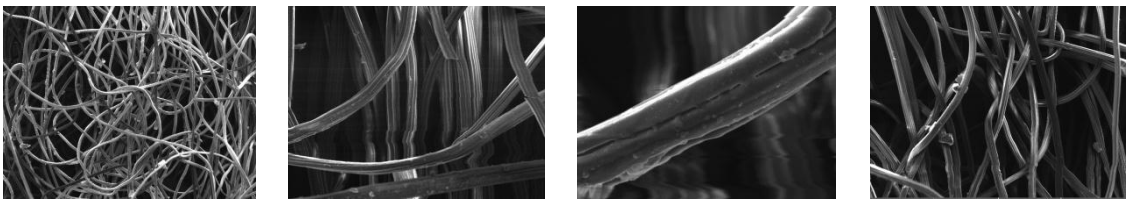
From the FT-IR traces for the bamboo, cotton and polyester fibres, it may be observed that different absorption bands in the spectra can be assigned from 4000 to 650 cm^{-1}. The absorption bands around 3500-3200 cm^{-1} are due to hydroxyl O-H stretching vibration [8], [9]. From the observation the O-H stretching may be associated with absorbed alcohols found in cellulose, hemicelluloses, lignin, extractives and carboxylic acids. The absorption band around 3100-2850 cm^{-1} is due to C-H stretching (Table3.3,) which is characteristic of any natural fiber. The presence of band at about 2150 cm^{-1} could not be identified with any molecular origin. The bands at 1740 cm^{-1} and around 1670 cm^{-1} may be related to C=O stretching observed in bamboo fibres, but this peak is not observed in cotton fiber as indicated in Table. 3.3. The characteristic wavelengths around 1374 cm^{-1} shared by hemicelluloses, cellulose and lignin, correspond to C–H stretching and deformation of $–CH_3$. The band at 1261-1255 $cm^{-1}$is due to possible C-O stretch vibration in lignin, acetyl and carboxylic vibration in xylan. On the other hand, 1154-1145 cm^{-1} C-O-C is due to asymmetric stretch vibration in cellulose and hemicelluloses. The absorption band at <1080 cm which is present in bamboo and cotton fibre [10].

Characteristic absorption bands of polyester fibres are at 1709, 1237, 1088, and 718 cm^{-1}. The weak absorption band at 2964 cm^{-1} is due to $– CH_2 –$ groups, 1709 cm^{-1} is due to carbonyl (C=O) stretching vibration, 1237and 1088 cm^{-1} to C–O vibrations. The absorption band at 718cm^{-1} is attributed to the benzene ring absorption. The band at 1405 cm^{-1} arises due to methylene groups in the PET fibre. These results are consistent with the previous studies about on polyester fibres.

Scanning Electron Microscope studies

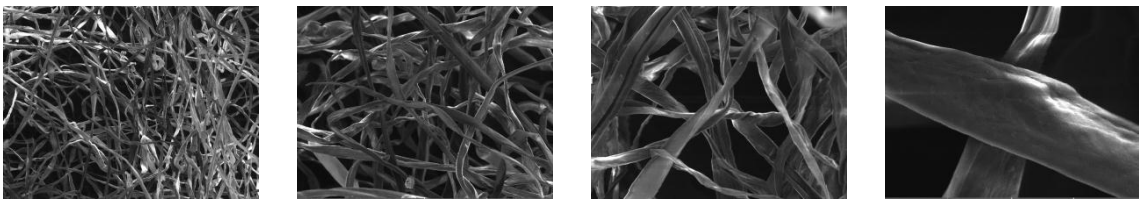
The longitudinal section of bamboo, cotton and polyester fibres for different magnification viz; ×200,500,1000and 5000 are presented in **Fig.4, 5and 6 (a), (b), and (c).** From the SEM images it can be observed that the longitudinal section of bamboo fibre is similar to the conventional viscose fibre. The bamboo fibre bundles were gummed by 15-20 single fibres. There were no nodes in the longitudinal surface of the bamboo fibre which is different from cotton and polyester. The surface of the fibre becomes rough and consists of many micro gaps which make the fibre more hygroscopic. The polyester fibre shows smooth surface with higher orientation. The cotton fibre surface was flat with a twisted ribbon like structure caused by spiralling of cellulose fibres. The presence of

natural folds running parallel along the cotton fibre axis was observed. The surface of the fibre was smooth.



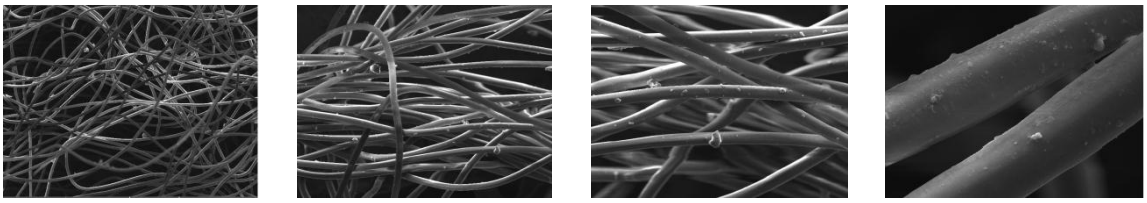
X200 X500 X1000 X5000

Fig. 4 (a) Longitudinal view of bamboo fibre



X200 X500 X1000 X5000

Fig. 5 (b) Longitudinal view of cotton fibre



X200 X500 X1000 X5000

Fig.6 (c) Longitudinal view of polyester fibre

Density: From the results it was observed that polyester fibre shows lowest density (1.38 g/cm^3) compared to cotton (1.53 g/cm^3) and bamboo viscose (1.51 g/cm^3).

DSC and TGA.

Table. 2 TGA results of bamboo, cotton and polyester fibres

Fibre samples	**Thermal stability (^{O}C)**	**Maximum temperature of decomposition (^{O}C)**	**Final temperature (^{O}C)**	**Residue (%)**
Bamboo	297.96	333.74	520.94	6
Cotton	319.77	352.30	370.84	14
Polyester	405.78	431.78	448.48	15

Table.2 shows the TGA results of bamboo, cotton and polyester fibres.. From the results it was observed that in the first stage, moisture evaporation takes place at temperature region of 38.71^{0}C-76.03^{0}C for bamboo, 81.18 to 84.03^{0} C for cotton, and this stage is not found in polyester fibres as polyester fibre are highly hydrophobic. The weight loss in this stage was 10.01% for bamboo and 4.7% for cotton. The thermal stability temperature was 297.96^{0}C for bamboo fibres, 319^{0} C for cotton and 405^{0} C for polyester fibres. The second stage, decomposition continues in the temperature range of 297^{0}C-520^{0}C for bamboo 319.9^{0}C to 370.84 for cotton and 405.95^{0}C to 448.48^{0}C for polyester. Residue left is 6% for bamboo fibre, 14% for cotton and 15% for polyester fibres. Among the three fibres polyester fibres show maximum thermal stability temperature and a residue of (15%).

Physical properties

Table.4 Properties of bamboo, cotton and polyester fibres

Sample	**Bamboo**	**Cotton**	**Polyester**
Fibre length (mm)	35	32	35.5
Fibre fineness	1.81d*	4.36 micronaire (1.5d)	1.71d*

Fibre strength (gpd)	2.48	2.4	4
Elongation at break (%)	15.5	5.7	10
Moisture regain (%)	12.5	7	0.4
Moisture content (%)	11	6.6	0.3
Density(gm/cm^3)	1.51	1.53	1.38

d= denier

The physical properties of bamboo, cotton and polyester fibre viz; fibre length (mm), fineness, tenacity, elongation at break, moisture regain, moisture content and density (gm/cm^3) are presented in **Table 4**.

From the results following observations were made. The fibre length of bamboo, cotton and polyester are in the similar range i.e. 35, 30.25 and 35.5 mm respectively. The cotton fibre is finer (1.5d) compared to polyester (1.71d) where as bamboo viscose fibres shows finesses value of 1.81d.

It can be observed that polyester fibre is stronger (4.0gpd) compared to bamboo viscose (2.48gpd) and cotton (2.4gpd).This is due to the difference in the physical and chemical structure of polyester. The elongation of bamboo fibre is the highest (15.5%) compared to polyester and cotton (10% and 5.7%) and this shows that the bamboo fibre is more flexible compared to polyester and cotton.

Bamboo fibre shows highest moisture regain and content (12.5 &11% respectively) compared to cotton and polyester (7% & 6.6%and 0.4% and 0.3% respectively).This is due to the presence of voids and micro gaps present in the bamboo fibre compared cotton and polyester fibre. Cotton shows moderate moisture content and moisture regain and polyester which are hydrophobic in nature shows very less moisture content and moisture regain.

Conclusions.

The X-ray diffraction pattern of the three fibres was observed and from the results it was found that regenerated cellulose fibres with a cellulose II structure have peaks at $2^{\theta} = 15\text{-}16^0$ and 21.8^0 assigned to (101) and (102) reflection, respectively. From the figure it is observed that bamboo and cotton fibres have a cellulose II structure. The

intensity of peak at 2^{θ} =21.8^{0} is much higher than that of 2^{θ} =15-16.The X-ray crystallinity of bamboo and cotton found to be 35.48 and 67.43% respectively.

The polyester fibre shows fully developed crystalline structure with relatively enhanced crystalline orientation as shown by the intensity, sharpness and equatorial and off- equatorial reflections. The equatorial trace shown in the figure can be resolved into three crystalline peaks viz.010, 110 and 100 planes as 5.5, 3.9 and 3.4 nm respectively. Crystallinity(X %) for polyester fibre found to be 54%.

The bamboo fibre bundles were gummed by 15-20 single fibres. There were no nodes in the longitudinal surface of the bamboo fibre which is different from cotton and polyester. The surface of the fibre becomes rough and consists of many micro gaps which make the fibre more hygroscopic. The polyester fibre shows smooth surface with higher orientation. The cotton fibre surface was flat with a twisted ribbon like structure caused by spiralling of cellulose fibres. The presence of natural folds running parallel along the cotton fibre axis was observed. The surface of the fibre was smooth.

From FTIR analysis, it was understood that, the absorption bands around 3500-3200 cm^{-1} were due to hydroxyl O-H stretching vibration. This O-H stretching may be associated with absorbed alcohols found in cellulose, hemicelluloses, lignin, extractives and carboxylic acids. The absorption band around 3100-2850 cm^{-1} is due to C-H stretching which is characteristic of any natural fiber. The FTIR analysis of polyester fibres confirms the presence of methylene groups.

From the results of TGA and DTG curves it was observed that in the first stage, moisture evaporation takes place at a temperature region of 38.71^{0}C-76.03^{0}C for bamboo, 81.18 ^{0} to 84.03^{0} C for cotton, and this stage was not found in polyester fibres as polyester fibres are highly hydrophobic. The weight loss in this stage was 10.01% for bamboo and 4.7% for cotton. The thermal stability temperature was 297.96^{0}C for bamboo fibres, 319^{0} C for cotton and 405^{0} C for polyester fibres. The second stage, decomposition continue in the temperature range of 297^{0}C-520^{0}C for bamboo 319.9^{0}C to 370.84 for cotton and 405.95^{0}C to 448.48^{0}C for polyester. Residue left was 6% for bamboo fibres, 14% for cotton and 15% for polyester fibres. Among the three fibres, polyester fibres show maximum thermal stability temperature and residue left is also maximum in case of polyester fibres (15%) and minimum in case of bamboo fibres.

From the results of physical properties of bamboo, cotton and polyester, all the fibre shows similar length and cotton fibres are finer (1.5d) compared to polyester (1.71d) and bamboo (1.81d).The polyester fibres shows higher tenacity (4.0gpd) compared to cotton and bamboo (2.5 and 2.48 gpd) and this is due to the difference in physical and chemical structure of polyester fibre. Bamboo fibre shows good elongation (15.5%) compared to polyester and cotton (10 & 5.7%) and this is because the bamboo fibre is more flexible compared to polyester and cotton. Bamboo fibre shows good moisture content and moisture regain (12.5% and 11%) compared to cotton and polyester (7, 6.6 and 0.4, 0.33 respectively) and this is due to the presence of voids and microgaps present in the bamboo fibre. Cotton fibre shows moderate moisture content (6.6%) and polyester which is hydrophobic in nature show less moisture content (0.3%). The density of polyester (1.38 d) is lowest compared to cotton (1.5 d) and bamboo (1.51d).

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