2.0 EXPERIMENTAL (GENERAL)
2.1 Materials

2.1.1 Fibre

The raw jute reed of Tossa (*Corchorus olitorius*) variety used in the full range of present studies was obtained in one lot from a specific field of jute cultivation in Kalyagunge in Dinajpore district of West Bengal, India. Agronomical and associated constitutional and related variations were thus avoided as far as practicable. The fibre was graded as TD-3 (Tossa Daisee) as per Bureau of Indian Standard specification (IS:271:1987). The fibre examination report on grading parameters is given in table 5.

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Grading parameters</th>
<th>Average value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reed Length</td>
<td>3-3.5 m</td>
</tr>
<tr>
<td>2</td>
<td>Root content</td>
<td>8%</td>
</tr>
<tr>
<td>3</td>
<td>Defects</td>
<td>1%</td>
</tr>
<tr>
<td>4</td>
<td>Fibre fineness (Gravimetric method)</td>
<td>3.58 tex</td>
</tr>
<tr>
<td>5</td>
<td>Fibre strength (Bundle tenacity)</td>
<td>29.77 cN/tex</td>
</tr>
<tr>
<td>6</td>
<td>Bulk density</td>
<td>0.6</td>
</tr>
<tr>
<td>7</td>
<td>Colour and lustre</td>
<td>Creamish yellow to creamish brown</td>
</tr>
</tbody>
</table>

The middle region of the raw jute reed was taken for the present work. The reeds were cut into a length of 305 mm (12 inch) for ease of chemical processing and for trouble free spinning into yarns in the subsequent step using a miniature jute spinning system. The cut reeds cut into the specified length were cleaned and made free of loose sticks, dirt and dust manually.

The other physical characteristics and major chemical constituents of raw jute fibre taken were evaluated and are given in table 6 and 7 respectively.
### Table 6 — Physical characteristics of jute fibre used

<table>
<thead>
<tr>
<th>Sl. no.</th>
<th>Physical characteristics</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Moisture regain * (%)</td>
<td>12.90</td>
</tr>
<tr>
<td>2</td>
<td>Linear density * (tex)</td>
<td>3.58</td>
</tr>
<tr>
<td>3</td>
<td>Tenacity of single filament * (cN/tex)</td>
<td>43.6</td>
</tr>
<tr>
<td>4</td>
<td>Breaking Extension of single filament (%)</td>
<td>1.21</td>
</tr>
<tr>
<td>5</td>
<td>Bundle tenacity * (cN/tex)</td>
<td>29.77</td>
</tr>
<tr>
<td>6</td>
<td>Flexural rigidity * (cN-mm²)</td>
<td>61.19</td>
</tr>
<tr>
<td>7</td>
<td>Coefficient of friction 7 (fibre to fibre – parallel)</td>
<td>0.32</td>
</tr>
<tr>
<td>8</td>
<td>Surface Reflectance at 420 nm *</td>
<td>20.34</td>
</tr>
<tr>
<td>9</td>
<td>Colour strength (K/S value) *</td>
<td>1.56</td>
</tr>
<tr>
<td>10</td>
<td>Whiteness index (Hunter lab) *</td>
<td>55.63</td>
</tr>
<tr>
<td>11</td>
<td>Yellowness index (ASTM E-313, 1976) *</td>
<td>35.22</td>
</tr>
<tr>
<td>12</td>
<td>Brightness index (ISO 2470) *</td>
<td>24.70</td>
</tr>
</tbody>
</table>

### Table 7 — Major chemical constituents of jute fibre taken

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Per cent* of bone dry weight of fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose * *</td>
<td>62 ± 0.2</td>
</tr>
<tr>
<td>Hemicellulose * *</td>
<td>23 ± 0.5</td>
</tr>
<tr>
<td>Lignin * *</td>
<td>12 ± 0.1</td>
</tr>
<tr>
<td>Fats and waxes * *</td>
<td>1 ± 0.05</td>
</tr>
<tr>
<td>Pectins * *</td>
<td>0.8 ± 0.01</td>
</tr>
<tr>
<td>Ash * *</td>
<td>1 ± 0.03</td>
</tr>
</tbody>
</table>

*Average of five separate sets of testing
2.1.2 General Chemicals

Commercial grade sodium hydroxide pellets (assay, 98%), glacial acetic acid (assay, 99.5%, specific gravity, 1.05 g/cm³), hydrogen peroxide (50% w/w), sodium meta-silicate, tri-sodium phosphate, sodium chloride (common salt), sodium carbonate and a non-ionic surfactant based on polyoxyethylene (Ultravan JU from Hindustan Ciba Geigy) were obtained from the local chemical market. Other chemicals used, viz. Sodium acetate, di-sodium salt of ethylenediamine tetra-acetic acid (EDTA), potassium peroxy-disulphate ($K_2S_2O_8$) (assay, 98%), sodium periodate ($NaIO_4$) (assay, 99%), aluminium sulphate, sodium nitrite, copper sulphate, ferric ammonium sulphate, potassium permanganate, acrylamide, ethylene glycol, poly (ethylene glycol) (PEG 200, 400, and 4000), ethyl alcohol, benzene, sulphuric acid, sodium chlorite were of laboratory reagent (L.R.) grade from E Merck, India and PEG 1500 of laboratory reagent (L.R.) grade was from NOCEL, India. A textile finish grade amino (-NH$_2$) group containing polysiloxane (popularly known as aminosilicone) in emulsion form (25% silicone) supplied by L. N. Chemicals, India was also selectively used.

2.1.3 Enzyme

A commercial grade aqueous mixed enzyme preparation (Bio-cellulase ZK from Biocon India Limited) was used. It contained 34.81, 96.30 and 136.0 units of cellulase, xylanase and pectinase respectively per millilitre of the aqueous solution.

2.1.4 Dye

A reactive dye, Procion Green HE 4 BD (CI Reactive Green 19), supplied by ATIC Industries, Gujarat, India was used.

2.1.5 Jute Batching Oil and Its Emulsion

A commercial grade hydrocarbon based mineral oil commonly referred to as jute batching oil (JBO) (boiling point, 285°C, flash point, 130°C, Red-wood viscosity, 63 sec and density, 0.825 g/cm³), was used for preparation of oil-in-water emulsion; here, a polyoxyethylene based non-ionic surfactant was used as the emulsifier. The weight proportions of oil, water and emulsifier in the final emulsion was adjusted to 6% oil, 93.5% water and 0.5% emulsifier.
2.2 Methods

2.2.1 Treatment of Jute Fibre

(a) Treatment of Jute Fibre with Water, Surfactant, Steam and Alkali

Raw jute fibres were treated with plain water at 30°C, 55°C and at 100°C (boiling) for a specified time period (usually 30 min and 120 min as appropriately mentioned) by dipping the fibres in water maintaining a fibre to liquor ratio of 1:15. Raw jute fibre was also likewise boiled in 0.5% (w/w) aqueous solution of the selected non-ionic surfactant (Ultravan JU) for 30 min to assess the effect of surfactant action under boiling condition. The plain water treated jute reeds were then given a wash using water, hand squeezed and dried in air at room temperature. Dry raw jute fibre and wet (100% water pick up) jute fibre were subjected to the action of steam in a laboratory steam ager (made by EEC, Mumbai, India) under a gauge pressure of 1.1 kg/cm² corresponding to a temperature of 121°C for specified time periods (5 min, 15 min and 30 min respectively). After steaming, the jute fibres were dried in air. Raw jute fibre was also subjected to treatment with aqueous NaOH (0.5% and 1%) solution for 30 min and 60 min at 30°C (room temperature) and at 100°C. The alkali treated jute fibre was then successively washed with warm water, and 1.5% (w/w) acetic acid solution till it is free from alkali. The alkali-free fibre was washed again with plain water, squeezed and finally dried in air.

(b) Treatment of Jute Fibre with Oxidative Agents (H₂O₂ and K₂S₂O₈ and NaIO₄)

Raw jute fibre was separately treated with 3% hydrogen peroxide ¹⁹, ²⁰, ²¹ at 85°C for 2 h at pH 11, and with a combination of H₂O₂ and K₂S₂O₈ at room temperature (30°C) for 2 h also at pH 11 ²², ²³. The treated jute fibre in each case was washed with water and finally dried in air.

The recipes used for the oxidative bleaching treatments with H₂O₂ and with the combination of H₂O₂ and K₂S₂O₈ are given below (table 8):
Table 8 — Recipe and treatment condition for oxidative bleaching of jute fibre

<table>
<thead>
<tr>
<th>Chemical and treatment condition</th>
<th>Oxidative bleaching with H₂O₂</th>
<th>Oxidative bleaching with the combination of H₂O₂ and K₂S₂O₈</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Peroxide</td>
<td>—</td>
<td>3%</td>
</tr>
<tr>
<td>Potassium peroxodisulphate</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Sodium Meta-silicate</td>
<td>—</td>
<td>8%</td>
</tr>
<tr>
<td>Sodium hydroxide</td>
<td>—</td>
<td>0.7%</td>
</tr>
<tr>
<td>EDTA as sequestering agent</td>
<td>—</td>
<td>0.05%</td>
</tr>
<tr>
<td>Non-ionic wetting agent (Ultravan JU)</td>
<td>—</td>
<td>0.5%</td>
</tr>
<tr>
<td>Fibre to liquor ratio</td>
<td>—</td>
<td>1:15</td>
</tr>
<tr>
<td>PH</td>
<td>—</td>
<td>11</td>
</tr>
<tr>
<td>Time of treatment</td>
<td>—</td>
<td>2 h</td>
</tr>
<tr>
<td>Temperature</td>
<td>—</td>
<td>85°C</td>
</tr>
<tr>
<td>Process</td>
<td>—</td>
<td>Treatment was carried out in exhaust bath</td>
</tr>
</tbody>
</table>

Raw jute fibre was also separately treated with other oxidizing agents viz. potassium peroxodisulphate \(^{24}\) and sodium periodate \(^{25}\) under specified conditions \(^{24, 25}\). For peroxodisulphate treatment, the raw jute was soaked in an aqueous solution of 0.5% K₂S₂O₈ at 30°C for 5 min using a fibre/liquor ratio of 1:10 (w/w). The fibre was then squeezed to remove excess solution so as to maintain 100% wet pickup. The squeezed sample was then exposed to U-V light (from Phillips 500W ‘Mercury Bulb Tungsten Filament’ lamp) for 15 min to finally obtain relevant oxy-jute fibres. Oxidation of jute fibre using 4% NaIO₄ was done at 30°C for 30 min maintaining fibre/liquor ratio of 1:20 (w/w) employing a standard condition \(^{24}\). Oxy-jute fibre from periodate treatments was
washed with water and finally dried in air, without giving exposure to U-V light, however.

(c) Treatment with Monomeric/Oligomeric Glycols and Acrylamide

The oxy-jute fibres were separately treated with glycols (ethylene glycol (EG) and polyethylene glycols (PEG) of different molecular weight viz. PEG 200, PEG 400, PEG 1500 and PEG 4000) and with the monomer acrylamide (AAm) by pad - dry -cure method under specified conditions. Treatment using only acrylamide (AAm) monomer leading to graft copolymerization of the monomer on jute was accomplished at 70°C for 30 min using a selected oxy-jute (K₂S₂O₈-treated) fibre. The treated fibre in each case was washed with running water to remove the water soluble free homopolymer (PAAm) and the unreacted monomer, if any, and finally dried in air. Further thermal treatment of oxy-jute fibres (both K₂S₂O₈-treated and NaIO₄-treated) in the presence of different EG, and PEG samples was generally accomplished at 125 °C for 10 min under the influence of Al₂(SO₄)₃ as catalyst, maintaining its dose level at 5% on the weight of the selected fibre. For similar treatment of oxy-jute (K₂S₂O₈-treated) fibre in the presence of ethylene glycol (EG), however, use of Al₂(SO₄)₃ as the catalyst was avoided, as it had little additional influence in property improvement as revealed from independent preliminary trials. The oxy-jute fibre was also separately treated with a mixture of PEG 1500 and acrylamide in different weight proportions under conditions by pad (100% wet pick-up) – dry (at 70°C for 30 min) – cure (at 125 °C for 5 min) method under the influence of Al₂(SO₄)₃ as catalyst, taken proportionately on the weight of PEG.

(d) Treatment with Mixed Enzyme System

Raw jute fibre and selected pretreated jute fibres as above were then treated with the mixed enzyme preparation in aqueous solution under a specified condition at 55°C for 2 h at pH 4.8 (using sodium acetate- acetic acid buffer). After the enzyme treatment, the temperature of the bath was raised to 90°C, which was maintained for 20 min to deactivate the enzymes. The treated jute fibre was then washed with water and finally dried in air.
(e) Treatment of Jute with Aminosilicone

Raw jute fibre as well as enzyme-treated and bleached jute fibres were further treated with an appropriate dose of the selected aminosilicone emulsion system following padding with 100% wet pick-up, drying (90°C for 20 min) and curing (125°C for 5 min) keeping the pH of the padding bath at 4.8-5.0 (using an appropriate acetate buffer). After the treatment, the treated fibres were washed with water and finally dried in air.

(f) Treatment of Jute Simultaneously with Mixed Enzyme and Aminosilicone

Raw jute and bleached jute fibres were also simultaneously treated with enzyme and silicone systems at 55°C for 2 h at pH 4.8-5.0. The fibres were then passed through a padding mangle to squeeze out excess aqueous solution and dried at 90°C for 20 min when the remaining enzyme system was deactivated. The dried fibre was then passed to a temperature of 125°C for 5 min to effect any possible reaction leading to curing of the fibre substrate. The treated fibres were then washed with water and finally dried in air.

2.2.2 Processing of Raw (Untreated) and Treated Jute Fibre

(a) Bleaching of Jute Fibre

Bleaching of raw jute fibre and differently treated jute fibres was carried out using hydrogen peroxide as the bleaching agent at 85°C for 2 h at pH 11 and maintaining a fibre to liquor ratio of 1:15. A bleaching liquor of the following recipe and dose levels was used in each case:

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>g/100 g jute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Peroxide</td>
<td>3</td>
</tr>
<tr>
<td>Sodium Meta-silicate</td>
<td>8</td>
</tr>
<tr>
<td>Sodium hydroxide</td>
<td>0.7</td>
</tr>
<tr>
<td>EDTA (for complexing the heavy metal ions)</td>
<td>0.05</td>
</tr>
<tr>
<td>Non-ionic wetting agent (Ultravan JU)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*(Volume of bleaching liquor — 1500 ml)*

The bleached jute fibre in each case was washed with water and finally dried in air.
(b) Dyeing with Reactive Dye

Selected jute fibre (raw, selectively treated and bleached) was separately dyed at 2% shade depth using 0.2% aqueous solution of a selected reactive dye (Procion Green HE 4 BD), using a lab beaker dyeing unit (made by EEC, Mumbai, India) maintaining a dyeing temperature of 80 ± 5°C and fibre/liquor ratio of 1:10 and also using appropriate dose level of sodium chloride (70 g/l) and sodium carbonate (20 g/l) according to a method described in the literature. Initially, the dye solution and half the required amount of NaCl and wet fibres are entered in the dye bath at 50°C temperature. The temperature of the bath was raised upto 60°C within 15 min and then the rest quantity of NaCl was added to the bath. Further 10 min period was allowed during which the temperature of the bath was raised to 70°C when half the required amount of Na₂CO₃ was added to the bath. After a further period of 15 min over which the temperature of the bath was raised to 85°C, the rest of the Na₂CO₃ was added to the bath. After a specified overall time (1.5 h) of dyeing, the dyed jute fibres were washed with hot water, cold water, and a 0.2% detergent solution at boil (100°C) for 10 min; the fibre was further washed with hot water and cold water successively, squeezed and dried in air.

(c) Yarn Making

Raw jute (control fibre) and some selectively treated jute fibres that appeared prospective for having been endowed with improved ranges of mechanical and physical properties, were then conditioned and subjected to a spinning process for yarn making. For conditioning an emulsion of jute batching oil containing 6% oil was sprayed using a hand sprayer on each fibre sample separately to maintain an average of 1.5% oil content and nearly 35% moisture respectively on weight of fibre; the fibres were then kept in separate bins for piling or conditioning for 24 h as commonly practiced in jute mills. After 24 h, the fibres were successively processed through two miniature carding machines (a Breaker card followed by a Finisher card) and three miniature jute drawing machines to obtain a uniform sliver of parallelized fibres of desired weight per unit length (about 2475 tex). The sliver from the third drawing machine was further processed in a standard commercial finisher drawing machine to get much finer and more uniform sliver. This sliver was finally spun into yarn of a linear density of about 165 tex using a Mackie’s standard apron draft jute spinning machine imparting an optimum level of twist (215 twist per meter) using a flyer speed of 3800 rpm.
2.2.3 Assessment of Chemical Constituents and Properties of Jute Fibres and Yarns

(a) Estimation of Cellulose and Hemicellulose\(^{13,14}\)

2 g of oven dried raw jute fibre was treated with 0.7% NaClO\(_2\) solution at boil for 2 h at pH 4 - 5 for delignification. Thereafter, the residual matter was filtered on a tared, G-3 sintered-bed glass crucible, washed with distilled water and dried under vacuum before weighing. The residual fraction constituted a mixture of cellulose and hemicellulose. The hemicellulose fraction was then dissolved out by treating the residue with about 200 ml of 18% (w/w) NaOH solution at 20 - 25°C for 60 min. The residual matter that escaped dissolution in this step constituted the cellulose fraction. It was washed thoroughly with water, dried under vacuum and weighed. The loss in weight on NaOH treatment accounted for the hemicellulose content. Cellulose and hemicellulose contents were expressed in weight percent based on the initial weight of the oven dry jute fibre.

(b) Estimation of Lignin\(^{13,15,16}\)

2 g of oven dried raw jute fibre was treated with 100 ml of 72% H\(_2\)SO\(_4\) at about 20°C for 2 h to dissolve and partly decompose the carbohydrate fractions of jute. The acid was then diluted with distilled water to 3% sulphuric acid and was gently boiled. The contents were then cooled and the residual matter containing the lignin part was allowed to settle. It was filtered through a tared, G-3 sintered-bed glass crucible, washed with distilled water, dried and weighed. Lignin content (%) was expressed in weight percent based on the initial weight of the oven dry jute fibre.

(c) Estimation of Fats and Waxes\(^{17}\)

2 - 5 g oven dried raw jute fibre was extracted with about 250 - 300 ml of a mixture of ethyl alcohol and benzene (1 : 2, v/v) in a soxhlet apparatus for 72 h to remove associated fats and waxes from the fibre. The fibre was then dried, washed with ethyl alcohol and distilled water in successive steps before final drying under vacuum at 50°C. Fat and wax content was expressed in weight percent based on the initial weight of the oven dry jute fibre.
(d) Estimation of Pectinous Matter

2 g of oven dried raw jute fibre was treated with 0.5% solution of ammonium oxalate at 75-80°C for 8h. The treated fibre was then washed with distilled water until oxalate ion could no longer be detected. After overnight air drying at room temperature, the fibre was conditioned under standard atmospheric conditions of 65 ± 2% relative humidity at 27 ± 2°C. Pectinous matter content was expressed in weight percent based on the initial weight of the oven dry jute fibre.

(e) Determination of Ash

Ash content was determined by taking 2 g of oven dried raw jute a platinum crucible and appropriately heating it successively over a bunsen burner for 2 h and in a muffle furnace at about 650°C till a constant weight was obtained on cooling in a desiccator. Ash content is expressed was weight percent based on the initial weight of the oven dry jute fibre.

(f) Determination of Copper Number

Copper number of selected jute fibre giving a measure of its reducing character or aldehydic group content was estimated following the method of Schwalbe – Braidy

0.25 g of oven dried raw jute fibre sample was cut into small pieces and taken in a 100 ml conical flask to which was added a boiling mixture of 5 ml of 10% (w/v) aqueous solution of crystalline copper sulphate (solution-A) and 95 ml of a freshly prepared solution called solution – B, containing a mixture of NaHCO₃ (5% w/v) and Na₂CO₃, 10H₂O (35% w/v). After stirring, the mouth of the flask was covered and the flask was kept immersed up to the neck in a rapidly boiling water bath for 3h. The contents were then filtered under suction through a sintered-bed, G-3 glass crucible and the residue was successively washed with hot 1% (w/v) Na₂CO₃ solution and then with distilled water; the filtrate and the washings were discarded. Over the residue on the filter bed was poured 50 ml of hot solution – C (100 g of ferric alum and 140 cc concentrated H₂SO₄ per litre) and the residue was then washed with 2 N hot dilute sulphuric acid. The combined ferric alum and acid washings were titrated with solution – D (0.04N potassium permanganate solution). A control experiment was also performed by titrating 50 ml of
ferric alum solution (solution – C) using the said KMnO₄ solution (solution – D). The copper number was then calculated as follows:

\[
\text{Copper number} = \frac{(V_2 - V_1) \times 0.04 \times 0.06357}{W} \times 100
\]

\( V_1 = \text{ml of the 0.04 N, KMnO}_4 \text{ solution required for the control experiment.} \)
\( V_2 = \text{ml of the 0.04 N, KMnO}_4 \text{ solution required for the test sample.} \)
\( W = \text{oven dry weight in gram of the fibre sample.} \)

(g) Determination of Moisture Regain

The moisture regain of a selected oven dry jute fibre sample was determined by allowing equilibrium moisture absorption at 65 ± 2% relative humidity at 27 ± 2°C and finding out the weight gain (%) following ASTM-D2654-76 specification².

(h) Estimation of Weight Loss/Gain of Jute Fibre

The weight loss (or gain) of jute fibre due to a specific treatment was determined using the following relationship:

\[
\text{Weight loss (or gain) } \% = \left( \frac{W_2 - W_1}{W_1} \right) \times 100,
\]

where, \( W_1 \) and \( W_2 \) are the oven-dry weights of untreated (control) and treated fibre samples respectively.

2.2.4 Evaluation of Some Physical and Mechanical Properties of Jute Fibre

(a) Fineness of Fibre

The fineness of (untreated and treated) jute fibres was measured following the standard gravimetric method³ (cut and weight method) taking a cut length of 2 mm after giving an exhaustive hand combing to the jute reeds on fine gill pins. In each case, average weight of 50 single filaments, all conditioned under standard condition of 65 ± 2% relative humidity at 27 ± 2°C ³¹ was used to calculate out fibre fineness (linear density) which is expressed in the unit of ‘tex’, i.e., average weight in g for 1000 m length of fibre.
(b) Bundle Tenacity of Jute Fibre

The bundle tenacity of jute fibre was determined under a specified test condition using JTRL-jute fibre bundle strength tester (a balance type tester). The instrument is based on the principle of beam balance with two unequal arms. Each fibre bundle test specimen was of 0.25 mg in weight and 12.5 cm in length; however, a standard test length of 5 cm was maintained between two clamps holding the fibre bundles. From the end of the short arm of the instrument, the clamped fibre bundle is suspended, the other end of the bundle mounted on another clamp is fixed below. On the longer arm, a heavy load is driven slowly from the fulcrum which increases tension gradually on the bundle until it breaks. The position of the load indicates the breaking load in kg. A group of five such specimens were taken for each test and bundle tenacity of fibre was calculated as per following formula:

$$\text{Bundle tenacity in g/tex} = \frac{125 \times T}{M}$$

where, $T$ stands for the sum of the breaking load values of five bundles of fibres in kgf and $M$, the total mass of all the bundles in mg.

(c) Flexural Rigidity of Jute Fibre

A fixed weight (5 mg) of jute fibre bundle of prefix length (7 cm) was mounted on a horizontal platform in such a way that it overhangs in the front for a fixed length (5 cm), like a cantilever. A vertical load in the form of a fixed pre-weighed (25 mg) synthetic gum tape was stuck to the free end of the fibre bundle for 60s. The fibre bundle bends downward on application of the known load; the flexural rigidity in mg.mm$^2$ was evaluated from the angular deflection of the fibre bundle measured on a circular scale fitted round the horizontal platform. The following formula was used to calculate the flexural rigidity in mg.mm$^2$ for the fibre bundle:

$$\text{Flexural rigidity in mg.mm}^2 = \left(\frac{L^2}{2 \theta}\right) \times \left(W_2 + \frac{LW_1}{3}\right)$$,
where, \( L \) stands for length of overhung fibre bundle in mm, \( \theta \), the angular deflection in radian, \( W_j \), the weight of fibre bundle in mg/mm and \( W_2 \) is the fixed load in mg at the free end of the fibre bundle.

(d) Coefficient of Friction of Jute Fibre

Fibre to fibre coefficient of friction of specified jute fibres (raw or treated) was measured following the principle of inclined plane friction tester.\(^7\)\(^8\)\(^9\) A 36 cm long jute fibre bundle weighing approximately 3.5 g was taken to make the two pads of 5 cm width, one attached to a plate which constitutes the inclined plane, and the other to the sliding plate of the tester. The coefficient of friction correspond to the value of \( \tan \theta \), where \( \theta \) is the angle of the inclined plane at which downward slide of the sliding plate was found to first occur.

(e) Some Surface (Appearance) Properties of Fibre

The whiteness index (WI) (Hunter lab)\(^10\) yellowness index (YI) as per ASTM-E-313, 1973\(^11\) and brightness index (BI) as per ISO-2470, 1977\(^12\) of the surface of the jute fibre samples were measured following standard procedures and standard relationship using a computer aided Macbeth 2020 plus reflectance spectrophotometer. The initial jute fibre bundle was lightly combed and mounted on a cardboard to form a continuous pad of fibres before testing.

The surface colour strength of raw, treated, and dyed jute fibres was separately estimated in terms of \( K/S \) value\(^8\)\(^9\) measured at the \( \lambda_{max} \) (\( \lambda_{max} \) is 420 nm for control and differently treated jute fibres and 640 nm for the dyed jute fibres), using a computer aided Macbeth 2020 plus reflectance spectrophotometer. The following of Kubelka-Munk relationship was used for calculation of \( K/S \) value.

\[
K/S = \frac{(1 - R_{\lambda_{max}})^2}{2R_{\lambda_{max}}} = \alpha C_D
\]

where, \( K \) = coefficient of absorption,
\( S \) = coefficient of scattering
\( R_{\lambda_{max}} \) = reflectance of the substrate at \( \lambda_{max} \) wavelength
\[ \lambda_{\text{max}} = \text{maximum absorbance wavelength} \]
\[ C_D = \text{concentration of dye} \]
\[ \alpha = \text{a constant} \]

(f) **Scanning Electron Microscopy**

The surface morphology of fibre samples was examined at 20 KV using JEOL Scanning Electron Microscope (Model: JSM-5200), by preparing the sample with Gold-Palladium alloy coating.

(g) **X-ray Defractometry**

The wide-angle x-ray diffraction patterns were obtained using a Philips x-ray diffractometer (Model 1710) by rotation powder method. The radial scanning of finely cut fibre samples were taken with Nickel filtered CuK\(_\alpha\), 1.54\(\text{A}\) radiation at an operating voltage of 40 KV and a filament current 30 mA. The crystallinity percentage were calculated from the plot of integral intensity in arbitrary unit vs. diffraction angle in 2\(\theta\) varying from 10\(^{\circ}\) to 33\(^{\circ}\).

(h) **Differential Scanning Calorimetry (DSC)**

DSC analysis of raw and differently treated jute fibre samples was done using a Shimadzu differential scanning calorimeter (DSC-50), under flowing nitrogen (flow rate - 50 cm\(^3\)/min) at a heating rate of 10\(^{\circ}\)C/min, using a sample size of 2 mg over a temperature range from ambient (30\(^{\circ}\)C) to 500\(^{\circ}\)C.

(i) **Fourier Transform Infrared Spectroscopy (FTIR)**

Selected fibre (finely crushed) samples (3 mg) were examined in a double beam FTIR spectrophotometer (BOMEM, MB 104) using KBr disc technique.

2.2.5 **Evaluation of Spinning Process Performance**

(a) **Electrical Power Consumption During Mechanical Processing of Jute Fibre (Prior to Spinning Stage)**

The electrical energy requirement for processing of jute fibre in the carding unit prior to fibre spinning for yarn making was assessed by noting the readings on
the ammeter, voltmeter and a three-phase power factor meter attached to the carding unit. After allowing the card to warm up by continuous running, five readings of current (amperes) consumed were taken on empty running machine at 10 sec interval. Similarly, current consumed in amperes were taken during processing of (jute) fibres at the carding unit.

The power consumed was then calculated as per following formula\(^3\):\(^7\),

\[
\text{Active power in watts} = \sqrt{3} \times \text{Line current} \times \text{Line voltage} \times \text{Power factor}
\]

The power consumed on processing of jute itself was obtained by subtracting the average power needed to run the empty card from the average power needed to run the fibre loaded card.

(b) Evaluation of Fibre Droppings at Card

Fibre droppings at both breaker card and finisher card were evaluated separately. After passing a known weight of jute through the carding unit, the droppings collected on a polyethylene sheet spread on the floor below the respective carding units were collected and weighed together; fibre-dropping (%) was calculated on the basis of the initial total weight of the material run through the carding unit\(^3\).

(c) Assessment of End Breakage Rate During Spinning

The end breakage rate in spinning was evaluated by counting the total number of spinning breaks at all the running spindles during whole period of spinning of the sample and has been expressed in number of breaks/spindle/h.

2.2.6 Evaluation of Some Physical and Mechanical Properties of Jute Yarn

(a) Linear Density of Yarn

The yarn linear density (mass per unit length) is expressed in the unit of g/1000 m or ‘tex’; the measurement was based on mass of yarn of 30 turns\(^3\) wound on wrap reel of 230 cm circumference under a constant tension. Average of ten such tests was used to express the linear density of the yarn.
(b) Tensile Properties of Yarn

The tensile properties such as tenacity, elongation at break, initial modulus and work of rupture of selected yarns were evaluated using a computer aided Instron tensile tester, model 4411 after conditioning the test yarn at 65 ± 2% relative humidity at 27 ± 2°C temperature for 48 h. The gauge-length and crosshead speed were maintained as 610 mm and 300 mm/min respectively as per IS: 1670-1970 method 39. The work of rupture (area under the load – elongation curve) was directly obtained from the recorder. Quality number or quality ratio 40, 41 of the jute yarn is expressed conventionally as the ratio of \(100 \times \text{(breaking load in lb)} \)/ (linear density in lb/14400 yd).

(c) Flexural Rigidity of Yarn

The flexural rigidity of yarn expressed as specific flexural rigidity was measured by the ring-loop method 42, 43. For this, a mandrel of 3.12 cm diameter was used for the preparation of a yarn ring. The yarn ring was gently hung on a hook of standard size and the undistorted diameter was measured. A load of 0.004 g/tex 44 was suspended on the yarn ring for 60s and the diameter of the distorted ring was determined. Specific flexural rigidity of the test yarn was then calculated following a standard method and using following expression 45.

\[
\text{Specific flexural rigidity} = \left\{ \frac{0.0047 \times W}{2\pi r^2 \times \cos \theta \times \tan \theta} \right\} \times \left(\frac{\text{Linear density of yarn in tex}}{\text{tex}}\right)^2
\]

where, \(W\) is the weight of suspended load in mg and \(r\) is the diameter of the ring; \(\theta = 493 \times d/2\pi r\), and \(d\), the deflection of the bottom end of ring loop under the action of load.

(d) Diameter and Packing Fraction of Yarn

The packing fraction \(\phi\) of the yarn was calculated 46 from the knowledge of fibre density and apparent yarn density on duly accounting for its linear density and diameter. The yarn diameter was measured using Leitz microscope with a magnification of 30\(\times\) under a constant tension of 0.02 g/tex 42. The packing fraction \(\phi\) is expressed as:

\[
\phi = \frac{\text{Apparent Yarn Density}}{\text{Fibre Density}}.
\]
The fibre density was taken as 1.48 g/cc in the present study. The yarn density of the yams was calculated from the following relationship:

\[
\text{Yarn density} = \frac{1}{\text{Specific Volume of yarn}} \quad \text{in g/cm}^3
\]

The specific volume of yarn was calculated from the following expression:

\[
\text{Specific volume of yarn} = \frac{\text{Volume of Yarn of 1000 m}}{\text{Linear density of yarn in tex}} \quad \text{in cm}^3/g
\]

\[
= \frac{78500 \text{ dy}^2}{\text{Linear density of yarn in tex}}
\]

Where, dy is the diameter of the yarn in cm.

(e) **Mass Irregularity and Hairiness of Yarn**

Development of some irregularity in the mass of yarn of a given length is a distinct possibility as fibres are converted to yarn during spinning. A more uniform sliver or fibre strand would expectedly cause generation of fewer irregular sites in the yarn and would lead to lesser deviations from average mass per unit length. The irregularity of yams expressed as (i) percent mean deviation of mass per unit length (0.8 mm) (Um%), (ii) number (N_{50}) of thick places (characterized by \( = 150\% \) of average mass per unit length) and (iii) number (N_{50}) of thin places (characterized by \( = 50\% \) of average mass per unit length) and (iv) number of neps (characterized by number of places of 1 mm reference length having \( = 500\% \) of average mass per unit length) averaged over 100 m of yarn length in each case were evaluated using Uster Tester 3 (from Zellweger Uster, Switzerland) after conditioning the yarn samples at 65 ± 2% relative humidity and at 27 ± 2°C temperature for 48 h. Yarn hairiness was also measured using the Uster Tester 3 fitted with the optoelectronic attachment to measure the hairiness of yarn. It gives an overall dimensionless numerical value of hairiness in terms of hairiness index which is defined as the ratio of cumulative length of protruding fibres per unit length (measurement field length of 1 cm) of yarn."
(e) Rot Resistance of Yarn

Rot resistance i.e., resistance to microbial attack of selected yarn samples was determined using standard soil burial test developed for the purpose and expressed in the form of percentage retention of the tensile strength of the yarn made from raw (untreated fibre) in each case. For the soil burial test, a composted soil consisting of a thorough mixture of fertile garden soil, cow dung and sand in 2:1:1 weight proportions was used maintaining a moisture content of the composted soil at around 25-27%. The soil burial test for the yarn samples was conducted for different periods of time (7, 14 and 21 days respectively) using the composted soil ambient temperature (30 ± 2°C) in the conical pot. At the end of the specified periods, the yarn specimens were taken out, washed gently in plain water, kept covered in a beaker containing ethyl alcohol for two hours and finally dried in air. The tensile strength of jute yarn samples was evaluated before and after the soil burial process following a standard method detailed earlier.
References


40. H L Parsons, Jute, Handbook of Textile Technology, No. 4 (The Textile Institute, Manchester, UK), 18.

41. S N Kar, Quality Control in Jute Industry (A Kar, Kolkata, India), 1966, 103.


