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Effect of Chemical Softening of Coconut Fibres on Structure and Properties of Its Blended Yarn with Jute

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Abstract: Coconut fibres were subjected to chemical treatment to obtain softer and finer fibres, suitable to blend with other finer fibre like jute. The chemical softening recipe was optimized using Box-Behnken design of experiments as 40 % Na_2S, 10 % NaOH and 6 % Na_2CO_3, which notably reduced the fineness (33 %) and flexural rigidity (74 %) and improved tensile property of coconut fibre. Effect of softening of coconut fibre on its process performance was studied in high speed mechanized spinning system at different blend ratios with jute. Blending with jute assists in spinning of coconut fibre to produce yarn of 520 tex at production rate of 5-6 kg/h, as compared to 15 kg/day for hand spun 5300 tex raw coconut fibre yarn in manual system. Analysis of blended yarn structure in terms of packing density, radial distribution of fiber components (SEM) and mass irregularity were investigated. SEM shows yarns made from softened coconut fibre -jute blends are more compact than raw coconut fibre -jute blend yarns. Coconut fibres were preferentially migrated to core of the yarn. Major yarn properties viz., tensile strength, and flexural rigidity of raw and chemically softened blended yarns were compared against their finest possible 100 % coconut fibre yarn properties. Yarn made up to 50:50 chemically softened coconut fibre-jute blend showed much better spinning performance, and having superior property in terms of reduced diameter, higher compactness, strength, initial modulus and less flexural rigidity than 100 % raw, 100 % chemically softened coconut fibre rope, and raw coconut fibre-jute blend yarns.

Keywords: Chemical softening, Coconut fibre, Blend yarn, Yarn structure, Properties

Introduction

Fibre extracted from coconut husk (*Cocos nucifera L.*), a conventional secondary crop is used for household ropes and matting, due to its robustness, high durability, low cost and abundant availability in coastal areas of peninsular India and its subcontinent. FAO report [1] shows that there is a slow but steady growth of global export of coconut fibre and its products, may be due to growing consciousness for using eco-sustainable materials in developed countries. However, traditional method of fibre extraction (dipping coconut husk for 6-12 months at back water lagoon) and lack of scientific input for mechanized processing of the fibre to manufacture finer and good quality products inhibits its entry in to several other potential uses. The methods, extraction and rope manufacture causes drudgery followed by occupational diseases to the persons involved in this profession, especially to the women folk [2].

Ratt spinning, traditional hand spinning of coconut fibre to make rope (producing 15 kg/day) using a spinning wheel, requires three people at a time, is the most popular spinning system for coconut fibre for making household rope [2,3]. The ropes and subsequent fabric produced from this system may not excel in all respect, as it does not allow producing finer, stronger and uniform rope. The major drawback of the system is back braking manual work, low productivity (12-15 kg of yarn per day only), thicker (diameter 3.7 mm), high unevenness and much hairy yarn structure. Some reports [2-4] on development of semi-mechanized spinning using motorized spinning wheel is available. Recently, mechanized spinning system [5,6] using a set of machines for making yarn, having a synthetic filament in its core is available. The machines offered advantages of increasing the production rate and reduction of manual load. However, the technology did not see the light of commercial adoption, as there is no considerable improvement in terms of fineness, strength, evenness and hairiness of the rope. Potentiality of blending coconut fibre with other fibre is another area to improve processibility as well as the property performance of twisted strand (commonly referred as yarn) is yet to be explored. The production of fine yarn is the crying need to develop newer products. Earlier, an effort [7] was made to make jute-coconut fibre blended yarn, but not much scientific information was available. In the present work, potentiality of making jute- coconut fibre blend finer yarn has been studied extensively.

Coconut fibre possesses some major disadvantageous properties viz., high flexural rigidity, large diameter and low length to diameter (L/D) ratio, which restricts its high speed mechanical processing (spinning, weaving, nonwoven making). Some discrete works [3,7,8] on reduction in flexural rigidity of coconut fibre are reported. However, study on the subsequent spinnability is not available in the literature. Recently, present authors [9] reported an accelerated chemical retting method, which softens coconut fibre to a considerable extent. The treatment reduces the diameter, linear density and flexural rigidity of fibre. The developed process reduces the retting time substantially from 10 months to 2 hours.

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However, the chemical recipe was yet to be optimized systematically.

The aim of the present work is to provide an industrially viable spinning technology for coconut fibre based fine yarn with improved property performance as compared to yarn spun from 100 % coconut fibre in conventional manual system. A statistical design of experiment was used to optimize the chemical retting/softening recipe for treatment to obtain fine quality coconut fibres. Physical and mechanical properties of chemically softened coconut fibres were studied in detail to assess their spinning performance and compared with raw and backwater retted coconut fibres. The fibres were subjected to spin coconut fibre-jute blended fine yarn in a modified mechanized spinning system and spinning performance was studied. Finest possible 100 % raw and chemically retted coconut fibre yarns were made using conventional system. Property parameters of blended yarns were related with its structure *viz.,* packing density, blend irregularity. Mechanical properties (*viz.,* tenacity, elongation, initial modulus, work of rupture), hairiness, and mass irregularity of blended yarns were compared with those of 100 % jute, 100 % coconut fibres (raw and accelerated retted) yarns also. Effect of softening is assed in terms of correlation between the packing density and flexural rigidity of blended yarn made up of raw and chemically retted coconut fibre.

Experimental

Materials

Raw (unretted) and backwater retted coconut fibres (*Cocos nucifera Lin.*) were brought from Thiruvanantapuram, Kerala, India. Jute (*Corchorus olitorius Lin.*) fibre of Tossa Daisee variety (TD4) (IS 271, 1987) was procured from Murshidabad, West Bengal, India.

Chemicals

Sodium hydroxide (assay, 98 %), sodium carbonate (assay, 99.9 %), sodium sulphide (assay, 98 %), and glacial acetic acid (assay, 99.5 %), Ultravan JU (non ionic detergent), and industrial grade castor oil (all from E Merc, India) were used.

Methods

Optimization of Chemical Softening Formulation Using, Design of Experiment

Use of Na_2S, NaOH, and Na_2CO_3 for chemical softening of coconut fibre imparts much superior textile properties to the raw coconut fibre and are well comparable with the conventionally backwater retted fibre [9]. However the responses of the individual chemical and interaction treatments were need to be studied scientifically for fixing the optimum chemical concentrations in the final formulation [10-12]. Hence, the Box Behnken method of design of experiment was employed using the three chemicals as three variables i.e. sodium sulphide (X_1), sodium hydroxide (X_2), sodium carbonate (X_3) at three different levels to obtain the optimum chemical softening formulation, as shown in Table 1. A quadratic polynomial of the following form was used for analysis of the second order surface design having, 15 runs of experiments.

Table 1. Variables and their levels used in the experimental plan

Variable	Coded level		
	-1	0	1
Na_2S (X_1)	20	40	60
NaOH (X_2)	10	20	30
Na_2CO_3 (X_3)	5	15	25

$$Y = b_o + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} b_{ii} X_{ii} + \sum_{i<j}^{k} b_{ij} X_i X_j$$

where Y is the response of the experiments and b_i, b_{ii}, b_{iii} are the regressions coefficients. The experimental combinations for chemical treatments and the corresponding actual and predicted values are given in Table 2. The material to liquor ratio for all the above said chemical treatments were maintained to 1:15. The raw coconut fibres were treated according to the combinations and then successively washed with warm water, neutralized with 5 % (w/w) acetic acid solution, washed with plain water, and finally dried in air.

Optimization of Time and Temperature for Chemical Retting/softening Treatment

The optimized formulation was used for chemical softening treatment for different time periods from 1 h to 3 h at 100 °C at the steps of 0.5 h. The effect of temperature on optimized formulation was separately studied at the temperature starting from 60 °C to 140 °C at the steps of 20 °C, maintaining the time of treatment for 2 h. The chemically treated samples were analyzed for their flexural rigidity and tenacity to find out the optimum treatment condition for chemical retting of coconut fibre.

Preparation of Yarn Sample

Ratt (wheel) Spinning for Preparation of 100 % Coconut Fibre-based Yarns

Finest possible conventionally spun 100 % raw and 100 % chemically softened coconut fibre ropes of 5200 tex and 2100 tex respectively were made using hand spinning wheel as made in conventional system [2].

Preparation of 100 % Jute and Coconut Fibre-jute Blend Yarns

Raw, chemically softened coconut fibres (treated with the optimized chemical recipe) and raw jute streaks were conditioned before yarn making. Before conditioning, raw jute fibres are passed through a jute softener machines (consists of 33 pairs of fluted rollers) for removing of surface adhered impurities and dust. Coconut fibres were

Table 2. Observed value and predicted response for coconut fibre softening

Experiment no.	Na_2S (%)	NaOH (%)	Na_2CO_3 (%)	Flexural rigidity (cN-mm^2)		Breaking tenacity (cN/tex)		Coefficient of friction (fibre to fibre-parallel)	
				A	B	A	B	A	B
1	20	10	15	703	729	13.14	12.35	0.429	0.335
2	60	10	15	662	679	12.53	12.25	0.383	0.504
3	20	30	15	619	602	12.86	13.14	0.448	0.541
4	60	30	15	456	430	12.67	13.46	0.403	0.281
5	20	20	5	610	567	13.5	14.47	0.377	0.368
6	60	20	5	400	399	13.36	13.50	0.436	0.415
7	20	20	25	302	303	14.66	14.52	0.365	0.383
8	6	20	25	244	287	16.41	15.45	0.378	0.385
9	40	10	5	371	388	14.5	14.35	0.461	0.455
10	40	30	5	322	297	12.0	12.67	0.422	0.428
11	40	10	25	252	278	13.46	12.78	0.364	0.358
12	40	30	25	201	185	14.28	14.44	0.429	0.434
13	40	20	15	260	264	14.15	12.95	0.371	0.379
14	40	20	15	283	264	12.82	12.95	0.390	0.379
15	40	20	15	250	264	11.87	12.95	0.377	0.379

A: Observed value and B: predicted response.

initially processed using a willowing machine (Kumaran, model 2005/V1, 204) to open the fibrous mass and to remove very short fibres and pith (non-fibrous vegetative mass). An oil-in-water emulsion using castor oil and water emulsion was sprayed on jute and coconut fibres separately to maintain 2 % oil and 30 % moisture on weight of fibre. The emulsified jute fibres were then passed again through the jute softener machines for uniform dispersion of applied emulsion and stacked in layers in a closed bin for 48 h for conditioning as practiced in jute mills [13]. Coconut fibres were stacked separately for conditioning in a closed bin for 72 h. During stacking, the oil and water is evenly spread thorough out the whole fibrous mass by surface tension. Jute yarns were prepared using standard commercial scale spinning system for jute [13], which includes a passage of two carding machines for fragmentation of long jute streaks using pinned rollers followed by three stages of drawing machine using screw gill pin arrangement for improving fibre parallelization and to obtain a sliver of reduced weight per unit length. The yarn was then prepared by flyer spinning machine (Machie, Scotland) with a twist level of 170 turn/m keeping spinning spindle speed at 3600 rpm for producing jute yarns of linear density of 520 tex.

For preparation of coconut fibre jute blended yarn, conditioned coconut fibres were blended in different blend ratios with jute at the feed plate of first carding stage. The preparation of blended yarn were conducted at modified spinning system developed for processing of coconut fibre and jute blends, which consists of two run of first carding (for fragmentation, opening and mixing of component fibres) followed by three runs of gill cum attenuating machine [14], to obtain a sliver (uniform continuous sheet of fibres assembly) of desired weight per unit length. The sliver was finally spun into yarn of a linear density of about 520 tex using a overhung flyer spinning machine [14] developed for coconut at an optimum twist level using flyer speed of 3600 rpm.

Determination of the Optimum Twist for Preparation of Coconut Fibre-jute Blend Yarns

For determination of the optimum twist, a fleece of 50 % coconut fibre 50 % jute blend was spun in to yarn as mentioned above imparting five levels of twist (118, 138, 157, 177, and 199 turns per meter). The yarns of varying twist levels were tested for tensile strength using Instron tensile tester (model 5567) according to BIS 1670 [15] and the effect of tenacity at varying twist level is shown in

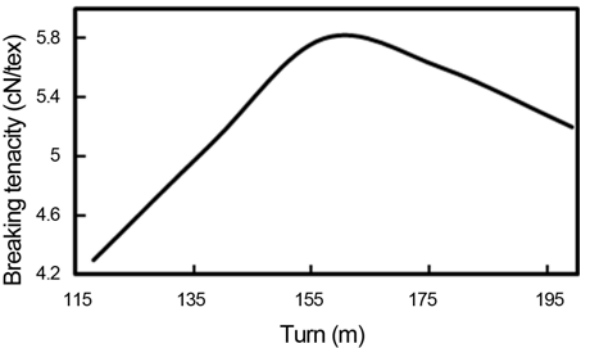

Figure 1. Relationship between breaking tenacity and turn per meter of raw coconut fiber jute (50:50) blended yarn.

Figure 1. Figure 1 indicated the twist level of 157 turns per meter was found to render the blended yarn highest breaking tenacity.

Conditioning of Fibre Samples

Coconut fibres were conditioned at an environment maintained at a relative humidity of 65±2 % and temperature of 27±2 °C for 48 h, before testing the property parameters as per IS recommendation [16].

Evaluation of Length, Diameter, Linear Density, Coefficient of Friction, Flexural Rigidity, Tensile, and Moisture Properties of Coconut Fibres

A set of 100 fibres chosen whose full length was measured separately. The same fibres were measured for their corresponding diameter, with a projection microscope with 30X magnification, and then weighed separately to calculate their linear density. Linear density of fibres was measured by gravimetric method [9].

Coefficient of friction was measured following the principle of inclined plane friction tester [17]. A bottom plate, hinged at one end (15.4 cm) and a top sliding plate (7.7 cm) were mounted with a set of fibre pad weighing 7 +/-0.5 g and 3.5 g +/-0.5 g respectively and placed in such way that the fibres in pad faced each other either in parallel or in perpendicular direction. The plate assembly was lifted by a string at one end to form an inclined plane. The coefficient of friction correspond to value of *tanø*, was measured from the length of base plate and raised height of inclined plate assembly at which first downward sliding of upper plate was observed. A total of 20 readings (each in parallel and perpendicular directions) were taken for each sample for the determination of fibre to fibre coefficient of friction.

The flexural rigidity was measured by ring-loop method using the following expression.

$$\text{Flexural rigidity (cN-mm}^2\text{)} = (0.0047WL^2 \times \cos\theta/\tan\theta)$$

where, W is the suspended load in cN and L is the perimeter of the ring; $\theta = 493d/L$ and d is the distortion of the ring loop under the action of load. A load of 1.114 g/tex was suspended on the fibre ring of 3.55 cm for 60 seconds and the diameter of the distorted ring was determined using the formula as described in fiber flexural rigidity testing [9]. A total of 50 readings were taken for each fibre sample.

The tensile properties of individual fibres, such as breaking stress (breaking strength/linear density of the unstrained length), breaking strain, tensile modulus and specific work of rupture of fibres were evaluated using Instron tensile tester (model 5567). The test length and strain rate were maintained at 50 mm and 20 mm/min. An average of 100 tests was taken for each case [9].

The moisture regain of oven dry coconut fibre samples were determined according to ASTM D 2654-76 by allowing equilibrium moisture absorption after conditioning under the standard conditions of 65±2 % RH and 27±2 °C for 48 h in a desiccator [18]. Twenty fibres of each type were immersed into water for 48 hours and then longitudinal swelling and transverse (diametrical) swelling was measured by projection microscope with 30× magnification.

Evaluation of Spinning Process

Fibre waste (in percentage of the weight of total fibre fed) at both breaker card and finisher card and moisture retention prior to spinning stage were evaluated using capacitance type moisture meter and yarn breakage rate in spinning was evaluated by counting the total number of yarn breaks at all the running spindles during whole period of spinning of the sample and has been expressed in number of break/spindle/h [19].

Evaluation of Properties of Yarn

All the yarns were tested for single strand mechanical properties using Instron tensile tester according to BIS 217 method following principle of constant rate of extension [20]. The test length and strain rate were maintained at 610 mm and 300 mm/min respectively. The tensile parameters were averaged from 75 observations from each yarn samples.

The packing fraction (ø) of the yarn was calculated from fibre density and apparent yarn density on duly accounting for its linear density and diameter. The diameter of the yarns was analyzed using NIKON SMZ 18 microscope at 120X magnification. The specific volume of the yarn was calculated according to linear density and diameter using following expression,

$$d = 0.00357 \sqrt{(V*N)} \times 10^{-3}$$

where, d is the diameter of the yarn in cm, V is the specific volume and N is the linear density in tex. The packing fraction ø is expressed as:

$$\text{ø} = \text{(Apparent yarn density) / (Fibre density)}$$

where, the yarn density (g/cm^3)=1/specific volume of yarn and the fibre density of the blended yarn was calculated using the following relationship,

$$\text{Fibre density of the blended yarn } (\rho) = (\rho_c\rho j /(P_c\rho_j + P_j\rho_c)) \times 100$$

where, P_c and P_j are the percentage of coconut fibre and jute fibre respectively and ρ_c and ρ_j, the densities of coconut fibre and jute fibre respectively [21].

The flexural rigidity of yarns was measured by ring-loop method. For this, a mandrel of 3.5 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 2.535 g/tex was suspended on the yarn ring for 60 seconds and the diameter of the distorted ring was determined using the formula as described in fiber flexural rigidity testing [22].

Yarn irregularity was determined using the Uster evenness tester (UT-III) tested at speed of 200 m/min for 5 min and an average of ten readings was taken. The hairiness per cm was measured under projection microscope (scale 1:30) and a

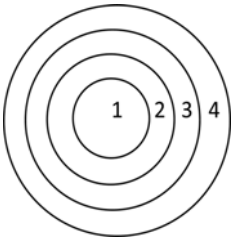

Figure 2. Concentric zones of blended yarn cross-section; zone 1: core, zone 2, zone 3, zone 4: surface.

total number of 50 readings were observed. Hair-length settings of 5 mm and 10 mm were selected and the number of hairs protruding from the yarn surface at the hair-length settings was recorded separately.

Evaluation of Blend Behavior of Strands/yarn

To estimate the blend behaviour of yarn, rotational distribution of component fibres was calculated from SEM micrograph of yarn cross-section as suggested by Salhotra [23]. The yarn cross-section was divided into four segments/ zones (Figure 2) and number of component fibres in each segment was counted. The blend ratio was calculated for each segment and an average of ten such results was taken to plot a histogram showing component fibres distribution.

SEM

The cross-sectional view of coconut fibre jute blend (40: 60) and 100 % jute yarns were examined at 20 kV using Philips XL-30 scanning electron microscope after preparing the samples with gold-palladium coating with a Sputter Emitech K550 to avoid electrostatic charge and to improve image resolution.

Results and Discussion

Optimization of Recipe for Accelerated Chemical Retting of Coconut Fibre

Table 3 shows that, regression coefficients for the flexural rigidity and breaking tenacity of coconut fibre. Table 3 indicating that the, there is a significant correlation between the observed and predicted values obtained for the flexural rigidity, and tenacity as tested through t-test at 5 % confidence level. The F value of 27.99 and P value (0.001) less than 0.05 is saying that the model terms are significant (Table 4 and 5). Tables 4 and 5 show a smaller value for standard error (S) 4.12 (flexural rigidity), and 0.02 (breaking tenacity), indicating a good fit of the models and a stronger linear relationship. The adjusted R-Sq for flexural rigidity (94.6 %) is marginally lower than its R-Sq (99 %), which indicates that even with the adjustment for adding extra variables (NaOH and Na_2CO_3) we still have a strong association in the model [24]. The significant variables were also identified in each of the fibre properties i.e., flexural rigidity and tenacity. It is evident from the first order coefficients (b_1, b_2, b_3) that, all the individual variables (*viz.,* Na_2S, NaOH and Na_2CO_3) have significant effect [25] on flexural rigidity and the negative value (Table 3) of it indicates that all the chemicals reduced the flexural rigidity of coconut fibre. The square term (b_{11}, b_{22}, b_{33}) indicates that, very high concentration of these chemicals tends to increase the flexural rigidity except for Na_2CO_3 (b_{33}). The

Table 3. Regression coefficients and correlation coefficient

Coefficient	Flexural rigidity	Breaking tenacity
Constant (b_0)	264.3	12.95
Sodium sulphide (b_1)	-94.3[a]	0.50
Sodium hydroxide (b_2)	-55.5[a]	0.06
Sodium carbonate (b_3)	-46 .0[a]	-0.01
Sodium sulphide*sodium sulphide (b_{11})	224.1[a]	0.39
Sodium hydroxide*sodium hydroxide (b_{22})	121.6[a]	-0.54
Sodium carbonate*sodium carbonate (b_{33})	-99.42[a]	1.15[a]
Sodium sulphide*sodium hydroxide (b_1*b_2)	-30.5[a]	0.11
Sodium sulphide*sodium carbonate (b_1*b_3)	- 38.0[a]	0.47
Sodium hydroxide*sodium carbonate (b_2*b_3)	-0.5	0.83[a]
Correlation coefficient	0.99[b]	0.87[b]

[a]Regression coefficient is significant at 95 % confidence level (Budett 1985) and [b]correlation coefficient between calculated and observed values was found to be significant through t-test at 5 % confidence level.

Table 4. Analysis of variance for flexural rigidity

Model	Degree of freedom	Sum of squares	Sum of squares	F	P
Regression	9	405480	405480	27.99	0.001
Linear	3	112635	206686	42.81	0.001
Square	3	283348	283348	58.68	0.000
Interaction	3	9498	9498	1.97	0.237
Residual error	5	8047	8047		
Lack-of-fit	3	7475	7475	8.70	0.105

S: 4.1177, R-square: 99.05 %, adjusted R-square: 94.55 %.

Table 5. Analysis of variance for breaking tenacity

Model	Degree of freedom	Sum of squares	Sum of squares	F	P
Regression	9	0.012937	0.012937	3.63	0.085
Linear	3	0.005450	0.006812	5.74	0.045
Square	3	0.004272	0.004272	3.60	0.011
Interaction	3	0.003215	0.003215	2.71	0.155
Residual error	5	0.001978	0.001978		
Lack-of-fit	3	0.001781	0.001781	6.04	0.145
Pure error	2	0.000197	0.000197		

S: 0.019891, R-square: 86.74 %, adjusted R-square: 62.86 %.

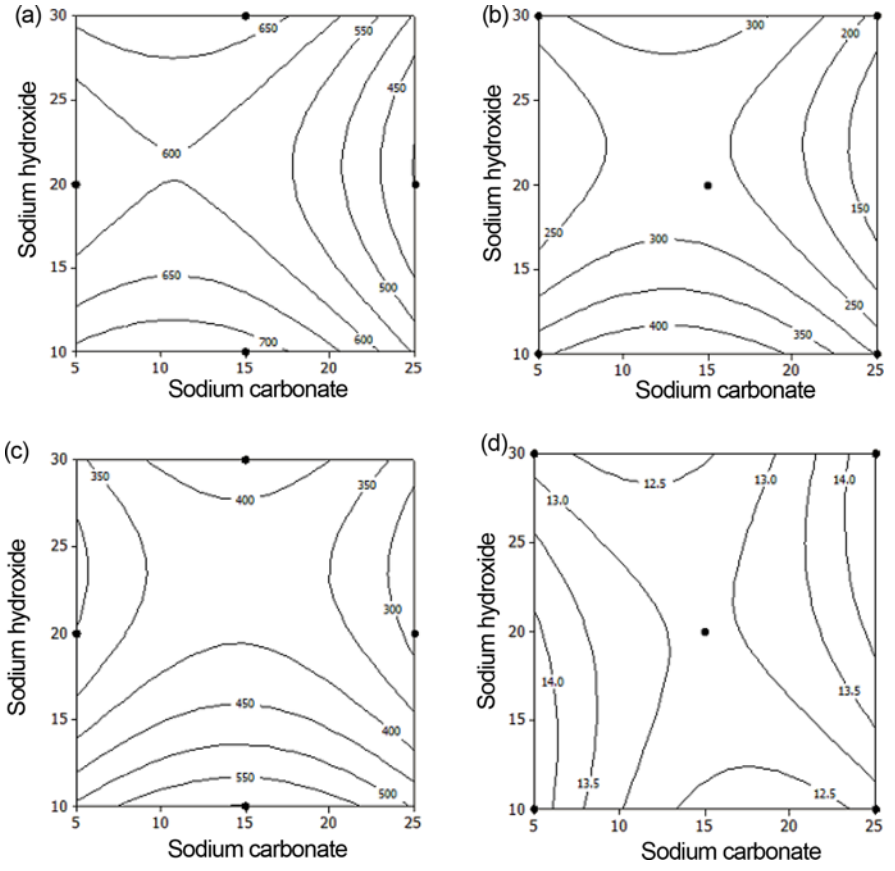

Figure 3. Contours showing interaction between Na_2CO_3 and NaOH for (a) flexural rigidity (constant conc., 20 % Na_2S), (b) flexural rigidity (constant conc., 40 % Na_2S), (c) flexural rigidity (constant conc., 60 % Na_2S), and (d) breaking tenacity (constant conc., 40 % Na_2S).

interactive effect of Na_2S and NaOH (b_{12}) and Na_2S and Na_2CO_3 (b_{13}) have significant effect on decreasing flexural rigidity. So it may be mentioned here all the three chemicals *viz.,* Na_2S, NaOH and Na_2CO_3, in combination, are essentially required to reduce flexural rigidity. Table 3 also shows that, all the variables have insignificant effect on breaking tenacity except for the square term b_{33} (high concentration of Na_2CO_3) and term b_{23} (interaction of Na_2CO_3 with NaOH). So it may be inferred that, Na_2CO_3 has a positive effect on the breaking tenacity of coconut fibre. The effects of the factors and interactions on the response (flexural rigidity and breaking tenacity) are shown in Figure 3. Figure 3(a), 3(b) and 3(c) show the contour curve for flexural rigidity, representing the interaction between NaOH and Na_2CO_3 at constant concentrations of Na_2S at 20 %, 40 %, and 60 % respectively. It can be seen from the figures that, with 40 % Na_2S, it is possible to reduce the flexural rigidity lesser than 300 cN-mm^2 (Figure 3(b)), which will produce fibre with sufficient softness, for spinning into finer yarn and is much softer than the conventionally backwater retted coconut fibre. Hence Na_2S concentration was optimized at 40 %. Keeping the 40 % Na_2S concentration, the corresponding contour graph for breaking tenacity was then studied. The contour curve (Figure 3(d)) shows that, both the combinations of 10 % NaOH with 6 % Na_2CO_3 and 19 % NaOH with 25 % Na_2CO_3 at 40 % Na_2S were giving better tensile property (breaking tenacity 14.0 cN/tex) on treated coconut fibre. For NaOH a lower concentration i.e. 10 % was fixed as the higher concentration has adverse effect on the fibre flexural rigidity and breaking tenacity. For Na_2CO_3, the lower concentration i.e., 6 % was preferable, considering the cost of chemical. So the final softening recipe was formulated to 40 % Na_2S, 10 % NaOH and 6 % Na_2CO_3.

The effect of temperature and time has some influence on the retting performance. However, to keep the process economic to the stake holder, it was decided that, temperature may be kept at 100 ^oC and the effect of time was varied from 1 to 3 h (Figure 4). Figure 4 shows that, flexural rigidity of the treated coconut fibre was reduced sharply (from 1173 to 312 cN-mm^2) from 1 h to 2 h of treatments and then it was nearly levelled off. This may be due to maximum removal of low molecular weight alkali soluble lignin of coconut fibre by 2 h, which loosen the structure and lessen the flexural rigidity considerably. However, the breaking tenacity which was initially increased from 11.3 to 14.5 cN/tex during treatments from 1 h to 2 h, reduced drastically beyond 2 h to

9.1 cN/tex. Initial increase in fibre strength may be due to of limited removal of lignin and carbohydrates up to 100 °C [9], which increase the cellulosic content of fibre and thus improve the strength. However treatment beyond 2 h, probably assisted in hydrolysis of cellulosic chain causing reduction in strength.

Effect of temperature was studied for chemical retting of coconut fibre using optimized formulation, as shown in Figure 5. The temperature was increased from 60 °C to 140 °C at steps of 20 °C. It was observed that, flexural rigidity was drastically reduced with increase in temperature up to 100 °C. Beyond 100 °C, there was little change on flexural rigidity, but tenacity was reduced drastically, which may be due to hydrolysis of cellulosic chain and removal of the fibre cementing material, i.e., lignin to a higher extent [26]. It is noteworthy that, aim of the work was to removal of lignin other non cellulosic contents in a controlled manner so that, fibre structure and mechanical properties does not get deteriorated. Hence, the treatment conditions of chemical retting were optimized to 100 °C for 2 h using the optimum formulation.

Physical, Mechanical, and Moisture Properties of Coconut Fibres

Table 6 shows physical, mechanical, and moisture properties of raw, conventionally backwater retted and chemically softened (optimized recipe) coconut fibre. Data infers obvious reduction in diameter of raw coconut fibre (320 μm) after its backwater retting (272 μm) and chemical retting (229 μm). However the extent of reduction is higher for chemical treatment, which in turns enhancing the length to diameter ratio of raw coconut fibre (915) nearly to length to diameter ratio of jute (1000). No change was observed in case of density values of raw, backwater retted and chemically softened coconut fibre. Coefficient of friction was also remaining unchanged. Mechanical behaviours in terms of breaking tenacity (from 11.3 to 14.5 cN/tex), initial modulus (from 200.8 to 253.7 cN/tex) have been improved considerably after the chemical retting than backwater retting (Figure 6). This may be due to higher leaching of hemicelluloses, low molecular weight lignin and other pectinous material, making the polymer chains structurally more consolidated [9]. The breaking extension for raw coconut fibre enhanced substantially from 21.5 % to 27.1 % and 34.6 % for backwater retted and chemically retted fibre respectively. The enhancement of extension, increases the work of rupture of both the backwater retted (20.6 mJ/tex-m) and chemically retted (38.4 mJ/tex-m) fibres as compared to raw (12.1 mJ/tex-m) coconut fibre. Table 4 also shows that the chemical treatment cascaded flexural rigidity of raw fibre (from 1173 cN-mm^2 to 317 cN-mm^2). This is mainly due to substantial reduction in diameter as well as removal of lignin and partial polymeric chain scission [9]. However, it may be noted that flexural rigidity of chemically treated fibre is still higher than jute. Chemical treatment also enhanced the moisture absorption (58 % to 108 %) and moisture regain (11.7 % to 13.7 %) of raw coconut fibres. This may be attributed to removal of hydrophobic surface layer and increase in pore sizes making easily accessible for water adsorption and absorption, which is also revealed from the increased transverse swelling and water absorption capacity.

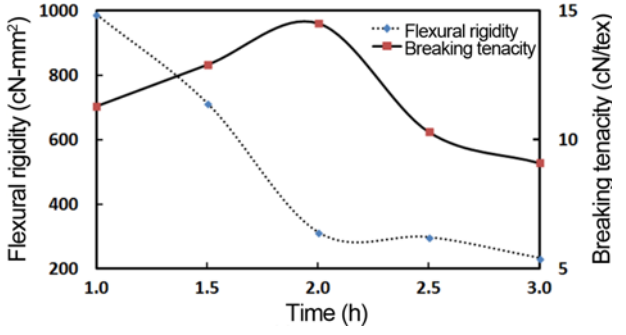

Figure 4. Effect of time of treatment on flexural rigidity and tenacity.

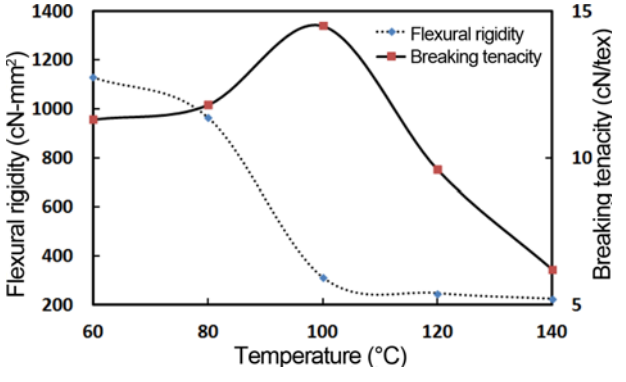

Figure 5. Effect of temperature of treatment on flexural rigidity and tenacity.

Spinning Process Performance

Looking into wide differences in extensibility (coconut fibre, 21.5-34.6 % and jute, 1.8 %), modulus (coconut fibre, 200-254 cN/tex and jute, 1900 cN/tex) and diameter (coconut fibre 320-230 μ for and jute, 60 μ) a modified jute processing system was developed to spin jute- coconut fibre blend yarn [12]. An effort was given to make yarn from blends as fine as possible. It was planned to make yarns from 420 tex at the steps of 50 tex. It was possible to make yarn of 520 tex in the spinning system with reasonable process performance at a rate of 16-17 m/min producing 5-6 kg/h, as compared to 12-15 kg/day for 5300 tex of raw coconut fibre rope respectively. In this context, it may be noted that, finer yarns always get premium price for its improved property performance.

Table 7 shows the spinning process performance of coconut fibre in blends with jute. Fibre loss as droppings at carding machines reduced notably for chemically softened

Table 6. Physical and mechanical properties of different coconut fibre

Property parameter	Raw	Backwater retted	Chemically treated	Jute
Physical parameters				
Diameter (micron)	320[a] (50)	282 (39)	229 (39)	60(32)
Length (mm)	183[b]	184	190	60[c]
Length-diameter ratio	750	748	915	1000
Linear density (tex)	49.01	44	33	3.8
True density (g/cm^3)	1.40	1.38	1.42	1.48
Apparent density (g/cm^3)	1.17	1.18	1.15	1.23
Baulk density (g/cm^3)	0.43	0.43	0.43	0.48
Coefficient of friction				
Fibre to fibre - parallel	0.31	0.37	0.33	0.48
Fibre to fibre - perpendicular	0.26	0.28	0.25	0.45
Mechanical behavior				
Breaking tenacity (cN/tex)	11.3 (54)	12.8 (37)	14.5 (43)	33.2 (45)
Breaking extension (%)	21.5 (51)	27.1 (37)	34.6 (42)	1.8 (41)
Initial modulus (cN/tex)	200.8	212.2	253.7	1900
Specific work of rupture (mJ/tex-m)	12.1	20.6	38.4	2.8
Flexural rigidity (cN-mm^2)	1173.6	546.81	312.43	22.1
Moisture relationship				
Moisture regain at 65 % RH (%)	11.7	12.8	13.7	13.5
Longitudinal swelling (%)	0.60	0.26	0.71	0.07
Transverse swelling (%)	17.0	30.60	34.80	25.0
Water absorption (%)	58	60	108	92

Figure in parentheses indicates coefficient of variation of the corresponding parameter; [a]range 100-795 μm, [b]range 44-305 mm, and [c]modal value of filament.

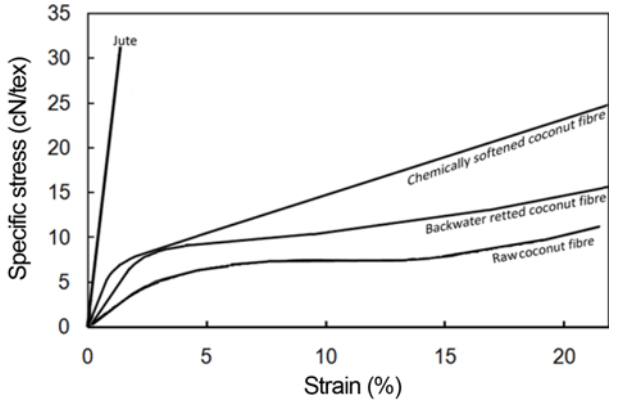

Figure 6. Stress-strain curve of coconut fibre raw (unretted), backwater retted, chemically retted and jute fibre.

fibre than raw coconut fibre at all blends ratios. This may be due to, better interaction between the machine parts and fibre, increased fibre to fibre cohesiveness owing to increased specific surface area (due to reduction in linear density from 49 to 33 tex), decrease in flexural rigidity and better water absorption capacity of chemically softened coconut fibre. Chemical softening of coconut fibre helped in easy bending of the fibres around the pins and rollers increasing better individualisation. It may be mentioned here that, in presence of jute, the specific surface area of the fibrous mass further enhances which increases fibre to fibre and fibre to machine cohesiveness. So decrease in jute content (consequently increasing coconut fibre content), in the blends lowers frictional resistance and thereby reduced holding capacity of fibrous mass during processing in machine and increased the droppings (Table 7). Table 7 also shows that, the moisture retention by the sliver prior to spinning increased with increase in softened coconut fibre content. Yarn breakage rate at spinning machine also reduced after the chemical treatment as compared to raw coconut fibre blend yarn. This is mainly due to lower flexural rigidity and presence of higher moisture of chemically softened coconut fibre. It is revealed that, raw coconut fibre content in the blend above 50 % is not technically viable proposition considering its very high fibre droppage and excessive yarn breakage rate at spinning machine. Disintegration of sliver was another problem at the back of the drawing machine due to increase in coconut fibre content as observed during processing. The lesser droppings in case of chemically softened coconut fibre

Table 7. Spinning process performance

Blend (Coconut fibre : Jute) (%)	Fibre loss as droppings at carding machines[a] (%)		Moisture retention prior to spinning stage[a] (%)		Yarn breakage rate at spinning machine (No. of breaks/spindle/h)		Coconut fibre retention in yarn structure[a] (%)	
	Raw	Chemically softened	Raw	Chemically softened	Raw	Chemically softened	Raw	Chemically softened
0:100*	1.3 (11)		28 (8)		NIL		Not applicable	
10:90	4.3 (23)	1.8 (24)	28 (11)	31 (8)	1.0	NIL	4.2	8.1
20:80	4.4 (28)	2.3 (27)	27 (12)	33 (7)	3.0	1.0	13.8	17.1
30:70	4.9 (17)	2.9 (22)	29 (9)	33(14)	3.5	1.0	20.4	27.4
40:60	5.8 (35)	3.4 (32)	31 (10)	34 (11)	5.0	2.0	26.8	36.3
50:50	8.6 (24)	4.2 (28)	30 (7)	35 (6)	7.0	3.0	33.3	43.0
60:40	NS	4.7 (24)	NS	36(8)	NS	5.0	NS	52.9
70:30	NS	5.3 (22)	NS	38 (9)	NS	7.5	NS	61.3
100:0**	NA	NA	NA	NA	NA	NA	NA	NA

[a]Results are the average of five replications. *100 % jute yarn, **conventional hand spinning yarn from backwater retted coconut fibre (100 %). Figure in parentheses indicates coefficient of variation of the corresponding parameter. NS: spinning is not possible because of sliver breakage at drawing frames and at spinning frame and NA: not applicable.

also assist in increase in retention ability of coconut fibre in the yarn than that of the raw coconut fibre. The percentage retention of coconut fibre decreased with the increase in its weight in blend composition.

Structure and Property of Blended Yarn

Scanning electron micrograph (Figure 7(c)) of cross-sectional view of softened coconut fibre jute blend yarn showed that, softened coconut fibre migrated to the core of the yarn. This is an opposite observations reported [23,27] earlier, where it was commented that higher modulus component in a blend are preferentially migrated to the core of the yarn. While examining cross-section of 100 % jute yarn (Figure 7(a)), it was observed that in jute fibrous mass even after twisting, a hollow structure is formed, which was also envisaged earlier by Sur [28]. This is due to twisted wrap ribbon structure obtained by the preferential disposition of jute fibres at the surface of yarn matrix resulted out of high centrifugal force at flyer during mechanical twisting. The preferential migration of coconut fibre may be due to its longer length, and higher elongation than jute and its position after coming out from the spinning triangle. It is stated that, longer fibres tend to occupy the centre/core of yarn, while the shorter fibre tend to move outward [29]. The average length (18-19 cm) of the coconut fibre is much longer than average length (6 cm) of jute. In addition, coconut fibres, having comparatively lower modulus, are strained more due to drafting force as compared to jute. So, after coming out from the drafting region, coconut fibres try to attain lower energy level by migrating towards the centre of the spinning triangle and accommodated itself in the vacant portion of the core. Similar trend has been also observed in case of raw coconut fibre jute blend yarn (Figure 7(b)), however, in this case packing intensity of the yarn is

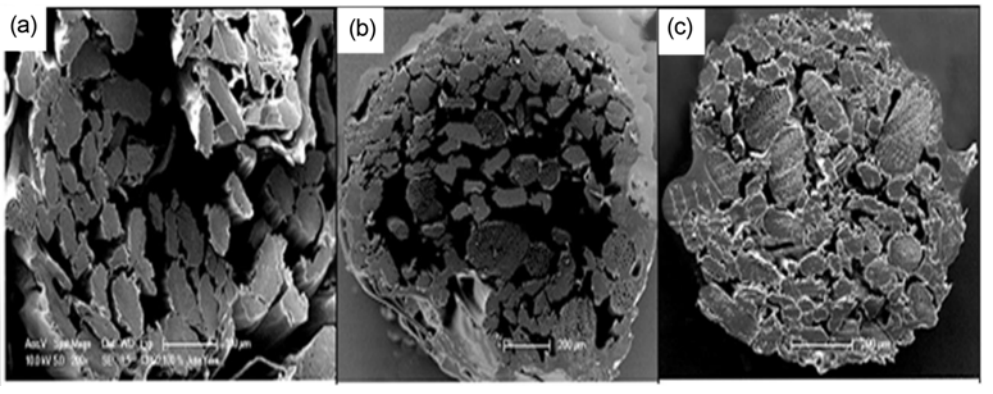

Figure 7. Scanning electron micrograph of yarn cross-section; (a) 100 % jute, (b) raw coconut fibre jute blend (40:60), and (c) chemically retted coconut fibre - jute blend (40:60).

much lower, may be due to higher flexural rigidity (Table 6) of unretted fibre, which hindered to get compacted during twisting. This is also reflected in terms of packing fraction values of both softened coconut fibre and unretted coconut fibre-jute blend yarn (Figure 8). Blend irregularity calculated by rotational distribution method (Figure 9) reveals that, maximum number of coconut fibres (47 % for chemically retted) were in the innermost segment (core). The outer most segment (surface) contained coconut fibres to the extent of 17 % and rest 83 % were jute fibre, which indicate that coconut fibres were mostly encapsulated by jute fibres, and thus improving overall surface appearance of the blended yarn.

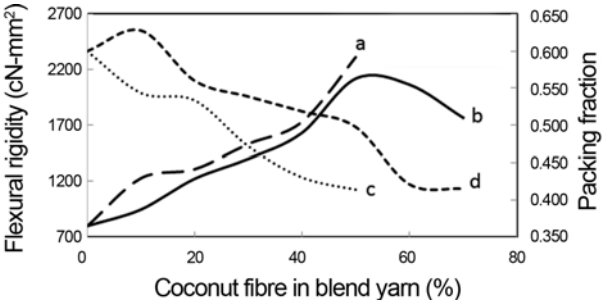

Figure 8. Relationship of coconut fibre content on flexural rigidity ((a) raw (b) chemically retted) and packing fraction ((c) raw (d) chemically retted)) of yarn.

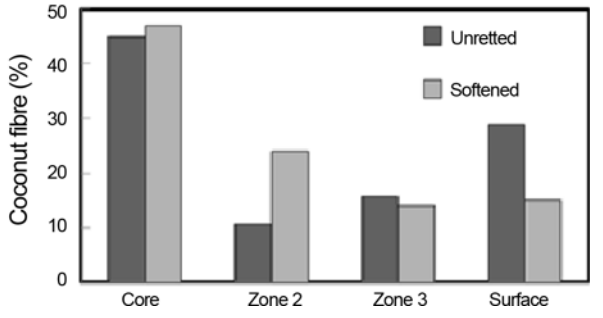

Figure 9. Distribution of coconut fibre in yarn cross-section.

Mechanical Properties of Yarn

Table 8 shows that, increase in coconut fibre (raw and chemically softened) content in the blend yarn, resulted in a decreasing trend of tensile properties in terms of breaking tenacity, initial modulus and work of rupture. During tensile loading, the core fibres have to bear the major axial load as they are oriented along the axis of yarn. Since, the weaker component (coconut fibre) migrated to the core, the resultant blend yarn showed lower tenacity values. In addition, decrease in number of fibres per cross-section as well as increase in number of coconut fibre having low coefficient of friction also caused decreased in tensile properties of the blend yarn. It may also be noted, in case of all the blend ratios, the tensile properties is found to be better for chemically softened coconut fibre based yarns as compared to raw coconut fibre based yarn. This may be due to improvement of fineness, length-diameter ratio, breaking tenacity of chemically softened coconut fibres and increased packing fraction of chemically softened coconut fibre jute blend yarn, which was discussed earlier. Figure 10 shows, thou the specific stress of raw and chemically softened coconut fibre are much lower than jute fibre, but due to much higher strain of 100 % raw (21.5 %) and chemically softened (31.6 %) coconut fibre yarn, the energy required to break the 100 % coconut yarn (4.0 mJ/tex·m) is much higher than jute yarn (1.24 mJ/tex·m). Initial modulus of raw coconut fibre yarn found to be very low as compared to jute yarn indicating its structural instability. However, blending

Table 8. Influence of blend ratio on yarn properties of raw and chemically softened coconut fibres

Blend ratio	Raw coconut fibre:Jute						Chemically softened coconut fibre:Jute					
Jute: coconut fibre	Breaking tenacity (cN/tex)	Breaking strain (%)	Initial modulus (cN/tex)	Number of hairs (m)		Yarn mass irregularity (U_m %)	Breaking tenacity (cN/tex)	Breaking strain (%)	Initial modulus (cN/tex)	Number of hairs (m)		Yarn mass irregularity (U_m %)
				> 5 mm	> 10 mm					> 5 mm	> 10 mm	
0:100*	11.3 (15)	2.4 (12)	280.9 (17)	19	19	20.8						
10:90	7.6 (17)	2.3 (18)	193.5 (18)	40	71	25.4	8.6 (23)	2.2 (18)	236.0 (18)	36	20	25.8
20:80	6.4 (21)	2.5 (21)	174.4 (18)	44	64	27.4	7.8 (22)	2.1 (19)	173.3 (21)	35	37	29.8
30:70	5.4 (21)	2.1 (19)	125.5 (19)	48	49	28.9	5.6 (24)	2.3 (20)	159.7 (19)	23	29	29.6
40:60	4.3 (26)	2.1 (17)	113.0 (24)	36	36	29.8	5.0 (23)	2.4 (19)	145.7 (17)	21	27	31.3
50:50	4.0 (19)	2.6 (16)	110.2 (17)	16	33	29.2	4.8 (23)	2.3 (22)	129.8 (14)	19	27	32.4
60:40	Not able to spin due to high breakage						4.3 (21)	2.7 (20)	115.0 (21)	20	9	31.5
70:30	Not able to spin due to high breakage						3.2 (38)	2.1 (35)	100.5 (32)	31	41	30.3
0:100**	3.6 (19)	19.5 (21)	21.2 (38)	-		-	3.8 (12)	28.7 (15)	14.4 (25)	-		-

*100 % jute yarn, **conventional manual spinning 100 % raw coconut fibre yarn (5200 tex) and chemically softened coconut fibre yarn (2100 tex). Figure in parentheses indicates coefficient of variation of the corresponding parameter.

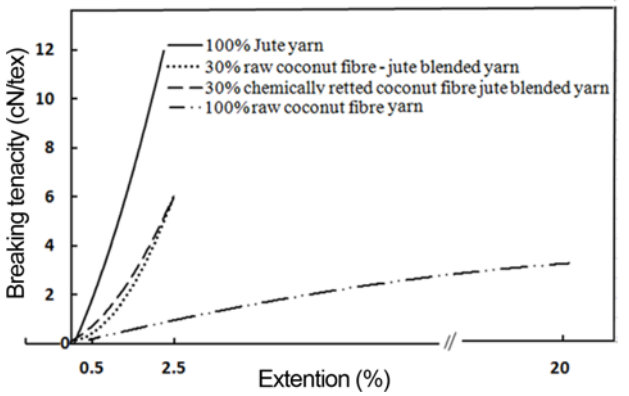

Figure 10. Stress-strain curve of 100 % Jute yarn; chemically retted coconut fibre jute blend yarn (40:60), chemically retted-jute blend (40:60) yarn, and 100 % raw unretted coconut fibre yarn.

of jute with coconut fibre improved the structural stability of the coconut fibre blend yarn.

Hairiness was notably lower in case of chemically softened coconut fibre jute blend yarn. This was due to better integration of fibre ends in to the yarn structure during spinning due to comparatively lower in flexural rigidity of chemically softened. It is also revealed that, most of the hairs protruding from the surface are more than 10 mm in length. Table 6 shows negligible difference between Uster evenness values for both raw and chemically softened coconut fibre blend yarn. However, there is trend of improvement in regularity in case of chemically softened coconut fibre blend yarn.

Conclusion

The optimized recipe was formulated for chemical softening of coconut fibre as 40 % Na_2S, 10 % NaOH and 6 % Na_2CO_3, at boil for 2 h, rendering much reduction in flexural rigidity (74 %), improved fineness (33 %), breaking tenacity (28 %), elongation at break (61 %), initial modulus (27 %), and moisture regain (17 %) making it suitable for spinning with jute for making of home textile applications viz., ornamental mattings, curtain, wall insulator, wall hanging, air filter, and handicraft items. Softened coconut fibre improved spinning process performance for making coconut fibre and jute blended yarn in high speed spinning system. Blended yarn from chemically softened coconut fibre and jute made in the ratio 50:50, showed much better spinning performance in respect of lower fibre loss and low spinning end breakage rate and the yarn were superior in terms of reduced diameter, higher compactness, initial modulus and less flexural rigidity when compared with raw coconut fibre-jute blend yarn, 100 % raw, and 100 % chemically softened coconut fibre rope. Minimum possible linear density of the blend yarn was found to be 520 tex at production rate of 5-6 kg/h, as compared to 15 kg/day for hand spun 5300 tex and 8 kg/day of raw and chemically retted coconut fibre yarn respectively. Raw coconut fibre content in the blend above 50 % is not technically viable proposition. Analysis of blend yarn structure through SEM showed preferential migration of coconut fiber at the yarn core, mostly encapsulated by the jute fibres, and thus overall surface appearance of the blended yarn was improved. All together, chemical softening and mechanized high speed spinning of coconut fibre blended yarn, resolves the age old problem of human drudgery involves in extraction and processing of the conventional secondary crop, hence improving the socio-economic conditions of coconut farmers and coir industry.

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