JOURNAL OF MECHANICAL ENGINEERING AND SCIENCES (JMES)
ISSN: 2289-4659 e-ISSN: 2231-8380
VOL. 14, ISSUE 4, 7622 – 7628
DOI: https://doi.org/10.15282/jmes.14.4.2020.26.0600

ORIGINAL ARTICLE

Influence of yarn parameters on cotton/kenaf blended yarn characteristics

S. A. S. Abdullah[1], N. Z. M. Zuhudi[1], K. D. Mohd Aris[1], M. N. Roslan[2], M. D. Isa[1]

[1] Malaysian Institute of Aviation Technology, Universiti Kuala Lumpur, 43800 Dengkil, Selangor, Malaysia
Phone: +60387688487; Fax: +6387688485
[2] Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Johor, Malaysia

ABSTRACT – Spinning kenaf fibers into yarns is challenging due to the stiffness and lack of cohesiveness of the fibers. Alkali treatment is known to remove hemicellulose, wax, and breaks down lignin, reducing stiffness of kenaf fiber and improving its spinnability. Kenaf fibers were treated at percentages of 4% and 6% and blended with cotton fibers at blend ratios of 40:60 and 50:50 prior to a ring spinning process to produce a double ply yarn of 70 tex. Yarn were twisted at three sets of twist. The responses were measured in terms of carding waste percentages and yarn strength. The results showed that the optimized yarn structural parameter is kenaf fiber treated at 6% and with a kenaf/cotton 40/60 blending ratio based on its tenacity and minimum carding waste. ANOVA shows that there is a good interaction effect between NaOH and kenaf/cotton ratio, and NaOH concentration and twist.

ARTICLE HISTORY
Received: 21st Nov 2019
Revised: 21st Apr 2020
Accepted: 12th July 2020

KEYWORDS
Kenaf fiber;
kenaf yarn;
kenaf/cotton blend;
spinnability;
alkalization

INTRODUCTION

Intensive exploration on environmental-friendly materials has led to the introduction of biofiber composites [1]. Fibers from banana, pineapple, sisal, jute, coir, etc. have been used in packaging industries, building, automotive, aerospace, textile, paper, and fiber board [2]. Natural fibers have the advantages of biodegradability, light weight and low environmental impact over conventional synthetic fibers [3]. Despite its promising future, the preform supplies of these fibers is limited to nonwoven which only provides for low strength applications. Recently, new varieties of unidirectional and woven biofibers have path the way for a high-performance biocomposite with its high strength, low density and ease of handling [4]. Kenaf in particular is known to have an advantage over other natural fibers due to its high stiffness, low density, short gestation period and is a highly resilient plant. However, due to its coarseness, stiffness and the low cohesion of fiber bundles, kenaf fibers are difficult to spin [5]. Spinnability is commonly measured by the amount of waste from the process and the quality of the spun yarn. Blending fibers with cotton for fiber spinning is a common method for fibers with low spinnability to achieve good quality yarns for apparel application [6].

The yarn structure is a function of many factors, the most important among them are mechanical properties of constituent fibers, fiber distribution along the yarn cross-section, and the relationship between the yarn structure elements, i.e. between the fibers (friction, various surface properties, number of contact points), determined by the spinning system, level of twisting, or chemical processing [7].

As bast fiber, kenaf has a higher stiffness-to-weight ratio as compared to cotton. However, the irregular form of the blended fibers aggravated by the bundled form of kenaf fibers cause unevenness in the kenaf-cotton blend, which leads to poor yarn quality [8]. Alkalization, a common surface treatment for biofibers is commonly used to separate kenaf fiber bundles by removing hemicellulose which acts as a binder between the fibers [4]. Alkalization also improves strength of individual kenaf fibers as removal of impurities improves the uniformity of the fibers. Tensile properties of kenaf fibers has been found to increase with treatment of up to NaOH concentration of 6%, whereas treatment of 9% degraded the strength of fiber cell walls [9]. Increasing twist tightens the lose fibers but also introduce an off-axis misalignment between the principal axis of the yarn and constituting fiber [6].

Kenaf is a new material with a good potential in composites application. Characterizing kenaf yarn from the many variations of process parameters will prepare kenaf for an industrial-scale manufacturing of green reinforcements. This experimental work studies the effect of alkali treatment of kenaf fibers, kenaf/cotton blend proportion, and twist level on yarn processing i.e. carding waste, and yarn quality, specifically tenacity. Statistical analysis was used to study the main effects of the response as well as the interaction effects between the factors.

METHODS AND MATERIALS

Kenaf fiber with enzyme retting extraction grade was obtained from Dynamic Agrofarm Sdn Bhd (Pahang, Malaysia) at the harvesting age of 4 months. Sodium hydroxide (analytical grade) pellets purchased from Merck Sdn. Bhd., Malaysia were prepared in 4% and 6% concentration. Kenaf fibers were cut into 100 mm length and immersed into a solution of

*CORRESPONDING AUTHOR | S. A. S. Abdullah | ✉ sfathinadlina@unikl.edu.my

the pre-determined NaOH concentration and 1.2% hydrogen peroxide. The mixture is then heated up to 90°C for 2 hours. Finally, the fibers were dried in a hot air oven at 60°C for a period of 24 hours to remove the excess moisture and cut into 4 cm length.

The kenaf yarns were prepared via a ring spinning process using cotton fibers as carrier. Figure 1 shows the cutting, opening and blending, carding, drawing, roving and spinning process. Kenaf and cotton fibers were first separately opened followed by a fiber-blending process in an opening machine in the designated proportions by weight. The next process is carding where the blended fibers were carded into a mat of 25 grams. The waste is measured and calculated back into the designated proportion of both fibers to ensure an accurate kenaf-cotton fiber ratio. Carding waste is recorded and analysed to determine readiness of the fibers to be spun. This is followed by a drawing process controlled by adjusting the draft ratio to obtain a drawn sliver of 4g/m. The slivers were again drawn in a roving machine to obtain slivers of 0.5g/m or 500 tex and a small twist of twist level 100. Finally the slivers were spun into yarns of 35 tex, with twist of 7.2 twist/cm. Two single plies are intertwined into an S-spin double-ply with tex of 70 via a doubling process.

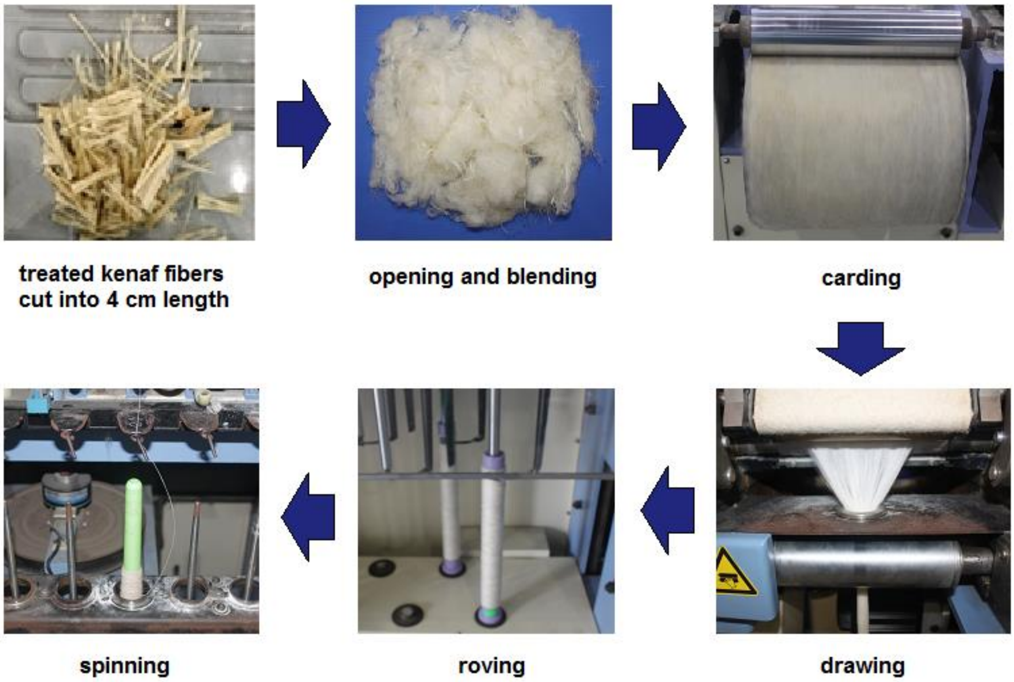

Figure 1. Process flow of ring-spinning kenaf/cotton blended yarn

The spinnability of the yarn is measured by its carding waste and the tenacity of the produced yarn. It was evaluated to determine the combination of material selection (concentration of NaOH treatment and kenaf/cotton blending ratio) and processing parameters (twist level) with the most significant effect. Fibers were treated at 4% and 6% NaOH concentration and yarns were produced to be of kenaf/cotton ratio 40/60 and 50/50. Three different twist level was set at low (70), medium (75), and high (80) setting which produces twist of 7.1 twist/cm, 8.1 twist/cm and 9.1 twist/cm respectively.

Yarns from untreated kenaf fiber (raw kenaf) were also fabricated at both 40/60 and 50/50 ratio to observe the effect of NaOH treatment, and yarns from 100% cotton fibers were fabricated to benchmark the effect of kenaf fibers inclusion into yarn. Design of experiment from Minitab 18 was used to obtain a randomized sequence of the spinning process. All the measurements are replicated twice. The weight of these yarn samples were measured in a climate room (65 ± 5% of RH at temperature of 20 ± 1°C) using a weighing balance. The yarn strength was tested in accordance to ASTM D2256 by a universal tension tester with 1kN load.

RESULTS AND DISCUSSION

Carding Waste

Carding is a process to reduce an entangled mass of fibers into a drafted and oriented web, separating fibers into single fibers and removing short fibers and impurities. However stiff kenaf fibers with its low interfibrillar cohesion tend to break and adhere to the drum and flats, as shown in Figure 2. The course bundled fibers were not able to hook itself in between the teeth of the carder and fall onto the collection tray as waste. Kenaf fibers also has low friction coefficient due to its smooth waxy surface [9].

The carding process is the first process that measures the spinnability of fiber. A high content of waste will indicate that the fibers are not ready for spinning and need prior pre-treatment. From the data collection of waste percent as shown in Table 1, it is shown that the untreated kenaf fiber has an unacceptably high carding waste of 43% and 44.2%. Treating the fibers with NaOH 6% shows a significant change, where the collected waste falls within the acceptable range (below 30%) at 24.3% and 26.6% for NaOH K/C 40/60 and 50/50 respectively. Alkalisation removes wax, hemicellulose and breaks down lignin that hold kenaf fiber bundles [10]. The disentanglement of bundles improves with NaOH treatment and NaOH 6% produced better pliability of fibers [7, 11]. Waste was also observed to be higher for 50/50 kenaf/cotton ratio, and thus limits the kenaf/cotton proportion at 50/50 as it is predicted to reach 30% at a higher kenaf content. A study by Zaida Ortega on the spinning of banana fibers into yarns shows similar results, whereby blending the fibers with either cotton, polyester and wool shows improvement on the ability to spin [12].

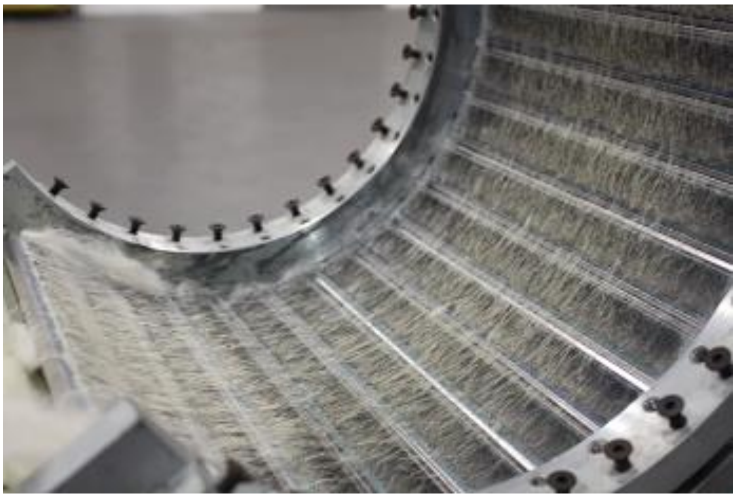

Figure 2. Waste on flats of carding machine

Table 1. Percentage of carding waste

Sample	Run 1		Run 2		Average	
	40/60	**50/50**	**40/60**	**50/50**	**40/60**	**50/50**
Raw kenaf/cotton	43.00%	49.50%	44.20%	53.30%	43.60%	51.40%
NaOH4%kenaf/cotton	25.50%	28.50%	24.90%	29.00%	25.20%	28.75%
NaOH6%kenaf/cotton	24.90%	26.30%	23.70%	26.90%	24.30%	26.60%

Image of Yarn

Figure 3 shows images of single ply cotton and kenaf/cotton yarn of ratio kenaf/cotton 40/60 and 50/50 magnified at 20x. Kenaf fibers were all treated with NaOH 6%. Cotton and kenaf fibers can be easily distinguished, as cotton fibers has a circular cross section, whereas kenaf fibers was seen to look like a filament due to the existence of kenaf fiber in a bundle form. These fiber bundles appear to stick out of the yarn, characterized as hairiness of the yarn. It can be observed that as the ratio of kenaf in yarn increases from 40% to 50%, hairiness of yarn increases. Diameter of kenaf/cotton yarn also increases as the irregularity of the fibers increases with inclusion of more kenaf fibers [13].The stiff kenaf fibers that tends to poke out of the yarn causes the surface of yarn to be rough. It can be observed that kenaf/cotton 50/50 has a higher hairiness as compared to 40/60 yarn.

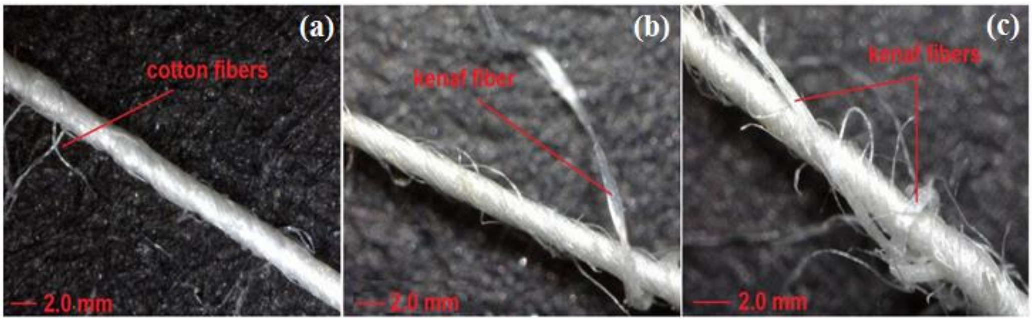

Figure 3. Single yarn of: (a) cotton yarn (b) kenaf/cotton 40/60 and (c) kenaf/cotton 50/50 (magnified at 20x)

Tenacity of Yarn

Tenacity is a measure of strength of yarn, defined as the ultimate breaking force of the yarn divided by the tex. Tenacity of kenaf/cotton yarns and 100% cotton as benchmark is as displayed in Figure 4. Results are taken from 10 yarns for each sample group with linear density between 32 and 37 tex and twist level of 70 (low level).

The graph shows that raw kenaf yarn of K/C 40/60 has only half the strength of cotton yarns. This is a common finding, as Ting Zhang reported upon blending with kenaf at 50/50 ratio, the yarn tenacity can drop for more than 50% [14]. Yarn is composed of successive links of fibre bundle, each gradually merges into its neighbour at either end. The low cohesion of kenaf fibers due to its waxy surface greatly contribute to the fiber slippage [15]. The irregularity of kenaf and cotton blend also speeds up the migration of the fibers [16]. This was also observed by T Karthik et. al. [17] with cotton/milkweed blended yarn where structures of ring-spun cotton/milkweed blended yarns have been characterized in terms of fiber migration, packing density and migration index to analyse the influence of yarn structure on yarn characteristics. The lower migration of cotton with the increase in milkweed proportion leads to less stitching of fibre bundles which results in the lower tenacity of yarns.

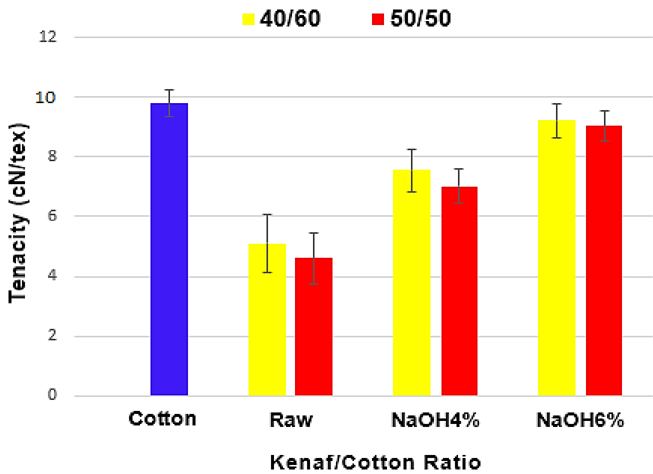

Figure 4. Influence of kenaf/cotton ratio and NaOH% on yarn tenacity of twist level 70

It is however observed that with an alkali treatment on the kenaf fibers, the tenacity increases and reached 9.6 cN/tex for NaOH 6% treated fibers at ratio of 40/60. Cohesion between fibers is improved with the partial removal of lignin and hemicellulose, exposing cellulose structure which improves fiber cohesion and improves mechanical interlocking [18]. Removal of waxy surface from hydrogen peroxide treatment also prevents fiber slippage. Alkalization is also a known treatment for natural fiber, by re-aligning of cellulose, improving the individual fibers crystallinity and strength [19]. This leads to a delayed fiber breakage that causes slippage, producing an improved yarn tenacity of kenaf/cotton yarns. This is in agreement with other findings which revealed that alkalization of cellulosic fibers improve softness and fiber strength[20]. It is also observed from Figure 4 that increasing kenaf content weakens yarn strength, however with NaOH concentration of 6%, the effect of higher kenaf content on tenacity is less significant. Only a slight drop from 9.6 cN/tex to 9.4 cN/tex was observed as kenaf content increased from 40/60 to 50/50 as compared to a more significant drop from 5 cN/tex to 4.5 cN/tex for raw kenaf yarn. Although kenaf/cotton blended yarn has slightly lower tenacity than cotton, it is known that preform strength is not directly proportional to composites strength and it is believed that kenaf fibers will contribute to a higher composites strength. Kenaf yarn also has various other attributes which includes being lightweight and having good hairiness which will contribute to good mechanical interlocking in composites application [8, 14, 21, 22].

Effect of Twist

Table 2 shows the tenacity of cotton yarns, untreated kenaf/cotton yarn and 4% and 6% treated kenaf/cotton yarns at ratio of K/C 40/60 and K/C 50/50 at different twist level. Fibers are twisted to induce lateral forces which act by means of friction to prevent the fibers from slipping over one another. Under-twisting cause early fiber slippage, whereas over-twisting yarns weakens fiber bundles, as making it oblique with respect to the yarn axis weakens the load distribution [17]. Three twist settings were chosen for low, medium and high, specifically twist level of 70, 75 and 80. Based on the results as shown in Table 2 it was observed that twist level 75 is the optimum twist for all the prepared yarn samples. Pre-testing of twist is important to ensure the twist chosen is optimized [23]. Other studies on twisting also shows the importance of characterizing yarn properties based on twist as one of yarn structural parameters [24–26].

Table 2. Effect of twist on tenacity

Treatment	Ratio	Tenacity (cN/tex)		
	kenaf/cotton	Twist 70	Twist 75	Twist 80
Cotton	-	9.82	10.05	9.61
Raw	40/60	5.1	5.57	5.07
	50/50	4.61	5.87	5.45
NaOH4%	40/60	7.57	6.86	7.82
	50/50	7.01	6.8	6.86
NaOH6%	40/60	9.22	9.37	9.12
	50/50	9.04	8.51	8.48

Statistical Analysis

The level of importance of the process parameters on yarn structural properties is determined by using analysis of variance (ANOVA). Analysis of the factorial design was done by Minitab 18 statistical software. Factors with P values <0.05 are considered as potentially significant. The result as presented in Table 4 proves all three factors i.e. NaOH, ratio and twist factor effect to be significant. It also shows that there is a good interaction effect between NaOH and kenaf/cotton ratio, and NaOH concentration and twist. As discussed, fiber treatment improves friction between fibers and overall enhanced yarn structural properties at a higher kenaf content. According to this set of data, ratio and twist is however not related. The behavior of kenaf fiber content in yarns and how it affects fiber slippage and twist has to be further addressed.

Table 3. Analysis of variance

Source	*df*	Meansquare	*F* value	*p*-value	
Model	17	4.7171	93.23	0.000	*significant*
NaOH	2	38.477	760.5	0	*significant*
Ratio	1	0.2246	4.44	0.049	*significant*
Twist	2	0.1874	3.7	0.045	*significant*
2-way interactions					
NaOH*Ratio	2	0.5216	10.31	0.001	*significant*
NaOH*Twist	4	0.2756	5.45	0.005	*significant*
Ratio*Twist	2	0.0182	0.36	0.703	*not significant*
Error	18	0.9107			
Total	35	81.101			

CONCLUSIONS

Kenaf/cotton yarn was successfully produced. Blended yarns are usually coarser than cotton yarns. Treatment with NaOH improves the spinning efficiency of the yarn by successfully reducing carding waste and upgrading the quality of the yarn by improving the individual strength of kenaf fibers and delaying fiber slippage. From this study, it can be concluded that:

1. Treatment of NaOH 6% reduces carding waste to half, making ring spinning process an efficient method of producing kenaf yarn.
2. Increasing kenaf content weakens yarn strength, however by increasing NaOH concentration to 6%, the negative effect of higher kenaf content on tenacity is less significant.
3. The optimized yarn structural parameter is Kenaf fiber treated at 6% and with a kenaf/cotton 40/60 blending ratio based on its tenacity and minimum carding waste.
4. As the purpose of the study is to study the feasibility of kenaf/cotton yarn as a preform for composites application, it is recommended that this study is expanded into composites fabrication and testing.

REFERENCES

[1] M. N. A. Nordin *et al.*, "Tensile and impact properties of pulverized oil palm fiber reinforced polypropylene composites: A comparison study with wood fiber reinforced polypropylene composites," *J. Mech. Eng. Sci.*, vol. 12, no. 4, pp. 4191–4202, 2018.

[2] A. Chafidz, M. Rizal, R. M. Faisal, M. Kaavessina, D. Hartanto, and S. M. AlZahrani, "Processing and properties of high density polyethylene/date palm fiber composites prepared by a laboratory mixing extruder," *J. Mech. Eng. Sci.*, vol. 12, no. 3, pp. 3771–3785, 2018.

[3] Q. Ahsan, T. S. S. Carron, and Z. Mustafa, "On the use of nano fibrillated kenaf cellulose fiber as reinforcement in polylactic acid biocomposites," *J. Mech. Eng. Sci.*, vol. 13, no. 2, pp. 4970–4988, 2019.

[4] M. Y. Haris, D. Laila, A. Zhahir, F. Mustapha, and M. Aris, "A Comparative Study of an Aircraft Radome Closed Mold through Vacuum Infusion Technique," vol. 576, pp. 690–694, 2012.

[5] A. Gherissi, "Failure study of the woven composite material: 2.5 D carbon fabric/ resin epoxy," *J. Mech. Eng. Sci.*, vol. 13, no. 3, pp. 5390–5406, 2019.

[6] W. Tao, T. A. Calamari, C. Yu, Y. Chen, and Y. A. N. Chen, "Kenaf / Cotton Blended Fabrics," *Text. Res. J.*, pp. 720–724, 1999.

[7] M. Rask and B. Madsen, "Twisting of fibres in yarns for natural fibre composites," *ICCM Int. Conf. Compos. Mater.*, pp. 1–6, 2011.

[8] P. Taylor *et al.*, "Effect of cotton waste and spinning parameters on rotor yarn quality Effect of cotton waste and spinning parameters," no. October 2014, pp. 37–41, 2007.

[9] T. Von Hoven, G. N. Ramaswamy, L. Kimmel, and E. Boylston, "Cotton/kenaf fabrics : a viable natural fabric," *J. Cotton Sci.*, vol. 3, pp. 60–70, 1999.

[10] S. A. S. Abdullah, N. Z. M. Zuhudi, N. I. S. Anuar, and M. D. Isa, "Mechanical and Thermal Characterization of Alkali Treated Kenaf Fibers," in *IOP Conference Series: Materials Science and Engineering*, 2018, vol. 370, no. 1.

[11] M. Chandrasekar, M. R. Ishak, S. M. Sapuan, Z. Leman, and M. Jawaid, "A review on the characterisation of natural fibres and their composites after alkali treatment and water absorption," *Plast. Rubber Compos.*, vol. 46, no. 3, pp. 119–136, 2017.

[12] Z. Ortega, M. Morón, M. D. Monzón, P. Badalló, and R. Paz, "Production of banana fiber yarns for technical textile reinforced composites," *Materials (Basel).*, vol. 9, no. 5, pp. 1–16, 2016.

[13] A. H. Alias, P. M. Tahir, K. Abdan, M. S. Salit, M. S. Wahab, and M. P. Saiman, "Evaluation of kenaf yarn properties as affected by different linear densities for woven fabric laminated composite production," *Sains Malaysiana*, vol. 47, no. 8, pp. 1853–1860, 2018.

[14] S. Mehmood and B. Madsen, "Properties and performance of flax yarn/thermoplastic polyester composites," *J. Reinf. Plast. Compos.*, vol. 31, no. 24, pp. 1746–1757, 2012.

[15] A. Ghosh, S. Ishtiaque, S. Rengasamy, and A. Patnaik, "The mechanism of end breakage in ring spinning: A statistical model to predict the end break in ring spinning," *Autex Res. J.*, vol. 4, no. 1, pp. 19–24, 2004.

[16] G. N. Ramaswamy and E. P. Easter, "Durability and Aesthetic Properties of Kenaf/Cotton Blend Fabrics," *Text. Res. J.*, vol. 67, no. 11, pp. 803–808, 1997.

[17] T. Karthik and R. Murugan, "Analysis of structural properties of cotton/milkweed blended ring, compact and rotor yarns," *Indian J. Fibre Text. Res.*, vol. 41, no. 4, pp. 361–366, 2016.

[18] M. N. Akhtar *et al.*, "Influence of alkaline treatment and fiber loading on the physical and mechanical properties of kenaf/polypropylene composites for variety of applications," *Prog. Nat. Sci. Mater. Int.*, vol. 26, no. 6, pp. 657–664, 2016.

[19] T. Karthik and R. Murugan, "Spinnability of cotton / milkweed blends on ring , compact and rotor spinning systems," vol. 41, no. March, pp. 26–32, 2016.

[20] L. Y. Mwaikambo and M. P. Ansell, "The effect of chemical treatment on the properties of hemp, sisal, jute and kapok for composite reinforcement," *Die Angew. Makromol. Chemie*, vol. 272, no. 4753, pp. 108–116, 1999.

[21] A. C. Mukherjee, A. K. Mukhopadhyay, A. S. Dutt, and U. Mukhopadhyay, "Liquid Ammonia Mercerization of Jute," *Text. Res. J.*, vol. 51, no. 9, pp. 574–578, 1981.

[22] S. Shi, C. Yang, and M. Nie, "Enhanced Interfacial Strength of Natural Fiber/Polypropylene Composite with Mechanical-Interlocking Interface," *ACS Sustain. Chem. Eng.*, vol. 5, no. 11, pp. 10413–10420, 2017.

[23] Y. Yang, J. Yu, H. Xu, and B. Sun, *Porous lightweight composites reinforced with fibrous structures*. 2017.

[24] E. S. kuthalam and P. Senthilkumar, "Optimization of spinning parameters influencing the hairiness properties of polyester/cotton vortex yarn," *J. Text. Inst.*, vol. 108, no. 3, pp. 449–459, 2017.

[25] H. Kawakami, M. Hashimoto, and F. Yamamoto, "Theoretical Estimation of End-Breakage Rate in Spinning," *J. Text. Mach. Soc. Japan - Trans.* -, vol. 24, no. 4, pp. T50–T57, 2012.

[26] N. T. Akankwasa, J. Wang, and Y. Zhang, "Study of optimum spinning parameters for production of T-400/cotton core spun yarn by ring spinning," *J. Text. Inst.*, vol. 107, no. 4, pp. 504–511, 2016.