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Study on Physical Properties of Sustainable Eco Yarns

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Abstract - The burgeoning need for sustainability in textile production has encouraged researchers to explore innovative fiber blends that not only reduce environmental impact but also maintain or improve textile performance. In this study, sustainable yarns were prepared by blending conventional cotton with a range of novel fibers including lotus, smartcel, kapok, lenzing refibra, cupro, sarona, and aloevera. Comprehensive evaluations of the yarns physical properties such as tensile strength, elongation, unevenness, hairiness, and friction were conducted under standard testing conditions. Detailed testing methodologies were adopted employing state-of-the-art instruments including the Premier Tensomaxx, Uster Tester 6, and Reseda Friction tester. The study also included cotton blended yarns with other natural & regenerated fibers as control samples. Results indicate that Cotton/Lenzing Refibra (60/40) blend is the overall best for both quality and industrial processing. It provides the highest combined tenacity and CSP, guaranteeing strong, long-lasting yarn. Maintains balanced friction characteristics for efficient manufacturing. It is good balance between evenness (U%), low hairiness, and low-to-moderate imperfection index (IPI). Provides added value by virtue of being eco-friendly and containing recycled material (a leading trend in international textile creativity and supply chain sustainability).

The implications of these findings extend both to industrial applications and future research into the development of high-performance eco-friendly textile material.

1 INTRODUCTION

The textile industry is one of the world's largest consumers of raw materials and water, and it consequently produces substantial environmental waste [1]. Among the various solutions proposed for enhancing sustainability, the use of natural and regenerated fibers has gained prominence. In recent years, mélange yarns—which combine different fibers to achieve aesthetic patterns and enhanced performance characteristics—have found applications in high-end apparel and technical textiles. Cotton, due to its softness, breathability, and wide availability, has traditionally been the fiber of choice. However, to align with eco-friendly practices and to reduce the ecological footprint of textile production, blending cotton with alternative fibers such as lotus, seacell, kapok, refibra, pineapple, sarona, and aloevera has been explored [2].

These fibers enjoy a sustainable profile owing to either their natural abundance or their status as by-products of other industries. For example, pineapple and refibra fibers are generated from agricultural residues, while lotus and seacell are recognized for their minimal environmental impact during cultivation and harvesting. The rationale behind such blending practices is twofold: to impart unique performance characteristics to the yarn while fostering sustainable production practices [3, 4]. Prior research has emphasized the potential benefits of fiber blending, particularly with respect to mechanical and surface properties. However, a comprehensive evaluation incorporating detailed testing methodology across several fiber types remains scarce.

The current study, therefore, seeks to fill this gap by examining and comparing the physical properties of sustainable yarns created by blending cotton with seven different fibers, including lotus, seacell, kapok, refibra, pineapple, sarona, and aloevera. The investigation centers on key quality metrics such as tensile strength, yarn unevenness, hairiness, and frictional properties. Each property is evaluated using standardized testing procedures under controlled laboratory conditions. The study further incorporates cotton-based blended yarns with other fibers as control samples to objectively assess the performance improvements contributed by each alternative fiber.

2 MATERIALS & METHODS

2.1 Materials and Yarn Preparation

A series of sustainable eco yarns were prepared by blending 60% cotton with 40% of one alternative fiber: lotus, seacell, kapok, refibra, pineapple, sarona, or aloevera. The BT cotton is used for spinning the yarn by blending with other fiber. Alternative fibers

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were procured from certified sources with documented environmental credentials. Prior to blending, all fibers were conditioned at 65 ± 5% relative humidity and 20 ± 2 °C for 48 hours to ensure uniform moisture content according to ASTM D1776 [5].

The blending process was performed using a precision fiber opener (blender) and carding machine to ensure homogeneous mixing of the fibers. The blended slivers were then spun on a ring spinning frame under standardized conditions. All yarn processing steps followed the protocols described by Li and Zhang (2019) [6] to minimize processing-induced variations in the properties. Control samples composed entirely of cotton and those of cotton blended with a traditional natural fiber (e.g., polyester or viscose as an industrial benchmark) were also prepared.

2.2 Testing Methodology

To carry out a comprehensive evaluation of the physical properties, separate testing methodologies were employed for tensile strength, yarn unevenness, hairiness, and friction properties. All testing procedures were performed under standard laboratory conditions (20 ± 2°C and 65 ± 5% relative humidity) as defined by relevant international textile standards.

2.2.1 Tensile Strength Measurement

Tensile strength measurements were performed using a Premier Tensomaxx Instrument. Specimens measuring 500 mm in length were tested at a constant rate of 100 mm/min. Each yarn sample was tested in accordance with ASTM D2256 [7], and the force required to break each specimen was recorded. A minimum of 20 replicates were conducted for each blending ratio, and the mean tensile strength & elongation was measured. The machine was calibrated prior to testing with standard weights to ensure accuracy.

2.2.2 Yarn Unevenness (U%)

Yarn unevenness was evaluated using an Uster Tester 6, a device that measures variations in yarn mass along the spinning length. The testing parameters were set to capture the % of mean deviation across a minimum testing length of 800 meters per sample. Following the procedures described by Uster Technologie [8], the device automatically corrected for external interferences including ambient fluctuations. Each sample was tested in triplicate to ensure reproducibility, and the resulting CV% values were used as a quantitative measure of yarn evenness.

For accuracy, the yarn samples were preconditioned and aligned in the tester's feed mechanism to avoid twisting or stretching during measurement. The use of a high-speed sensor ensured that variations in mass were captured in real time, providing a detailed representation of yarn consistency for each fiber blend.

2.2.3 Hairiness

Hairiness was quantified using Uster Tester 6, which measures the number and length of protruding fiber ends from the yarn surface. Following the method described Uster Technologies [8], yarn samples were mounted on a stand & hairiness automatically counted the number of hairiness filaments per unit length of yarn.

2.2.4 Co-efficient of Friction

Friction properties were assessed using a Reseda Friction Tester, a device specifically adapted for textile applications. The test procedure involved a standard and friction coefficients were calculated based on the resistance encountered by the yarn sample. The friction coefficient and wear behavior were recorded over the length of the test. This method, based on the standardized procedure provided in ASTM D3108/D3108M-13 [9], allowed for the comparative analysis of surface friction among the different yarn blends.

The friction evaluation was carried out under controlled conditions, ensuring that the effects of static electricity and ambient conditions were minimized. Data was logged digitally and cross-verified with manual observations, ensuring that the friction coefficients reported were consistent and reliable.

3 RESULTS & DISCUSSION

The testing of the sustainable yarns yielded a comprehensive data set that was analyzed to compare the physical properties across the different blends. In this section, the results of the tensile strength, yarn unevenness, hairiness, and friction properties are

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presented in detail along with comparative analysis between the cotton-based control samples and each of the alternative fiber blends.

Table: Properties of 100% cotton & cotton blended yarn with different sustainable fibers

S. No.	Count (Ne)	Blend (%)	CSP	U%	Imperfection Index	Hairiness (H)	Elongation (%)	Tenacity (gpt)	Coefficient of Friction (µ)
1	2/30	Cotton/LenzingRefibra(60/40)	2502	10.7	103	9.52	5.38	16.37	0.12
2	2/30	Cotton/Cupro (60/40)	2322	9.42	17	8.69	5.64	16.03	0.06
3	2/30	Cotton/Kapok (60/40)	1885	13.97	897	10.74	3.7	11.72	0.05
4	2/30	Cotton/Aloevera(60/40)	2111	9.11	14	8.93	4.77	13.1	0.06
5	2/30	Cotton/Lotus (60/40)	2249	10.18	193	9.81	5.27	12.9	0.14
6	2/30	Cotton (100)	2325	9.23	24	9.93	4.15	15.49	0.05
7	2/30	Cotton/Sarona (60/40)	2162	11.16	165	10.13	5.77	13.75	0.09
8	2/30	Cotton/Smartcel(60/40)	2017	10.35	50	8.42	5.2	13.12	0.18

3.1 Count Strength Product

The variation in the CSP with different blend (%) of all type of yarns given in the following figure 3.1. The Cotton/Lenzing refibra (60/40) blend has the CSP value with the largest lead by far, and it looks like it's just short of 2502.The lowest CSP value is for the Cotton/Kapok (60/40) blend, which is just about 1885. This indicates Kapok fiber is very severely weakening the yarn when mixed with cotton. The 100% Cotton control has a middle-of-the-pack CSP value, about which there is nothing noteworthy to say. This is an important reference point.

Cotton/Cupro, Cotton/Aloevera, Cotton/Lotus, Cotton/Kapok blend shows lower-strength yarns. This means that these fibers (Cupro, Aloevera, Lotus) possess lower inherent strength than cotton and function as a "filler" that detracts from the structural integrity of the yarn. Kapok is an extreme example; it is a relatively short, smooth, and brittle fiber that contributes little or no spinning cohesion, producing nearly useless yarn in terms of strength. The Cotton/Refibra (60/40) blend spun the strongest yarn. The Cotton/Kapok (60/40) blend spun the weakest of the blends tested. The 100% Cotton yarn provides a good standard, with many of the blends performing as well as or better than this. Key factors influencing CSP: fiber strength, length, uniformity, fineness, and cohesion. For Cotton/Refibra, highlight that Refibra is a high-tenacity and uniform regenerated cellulose fiber that increases spinability and stress distribution. Contrast that with Kapok's loose structure and low cohesion, resulting in slippage and poor yarns. The Cotton/Refibra blend marries the beneficial, natural spinning characteristics of cotton with the greater intrinsic strength and excellent binding ability of Lyocell, producing a yarn stronger than 100% cotton. The Cotton/Kapok blend is not strong because the kapok fibers are inherently weak, brittle, and cannot adequately hold onto their surrounding cotton fibers. Strength of the blend is very much less than that of 100% cotton since the kapok parts fail much earlier than the cotton parts reach their breaking point.

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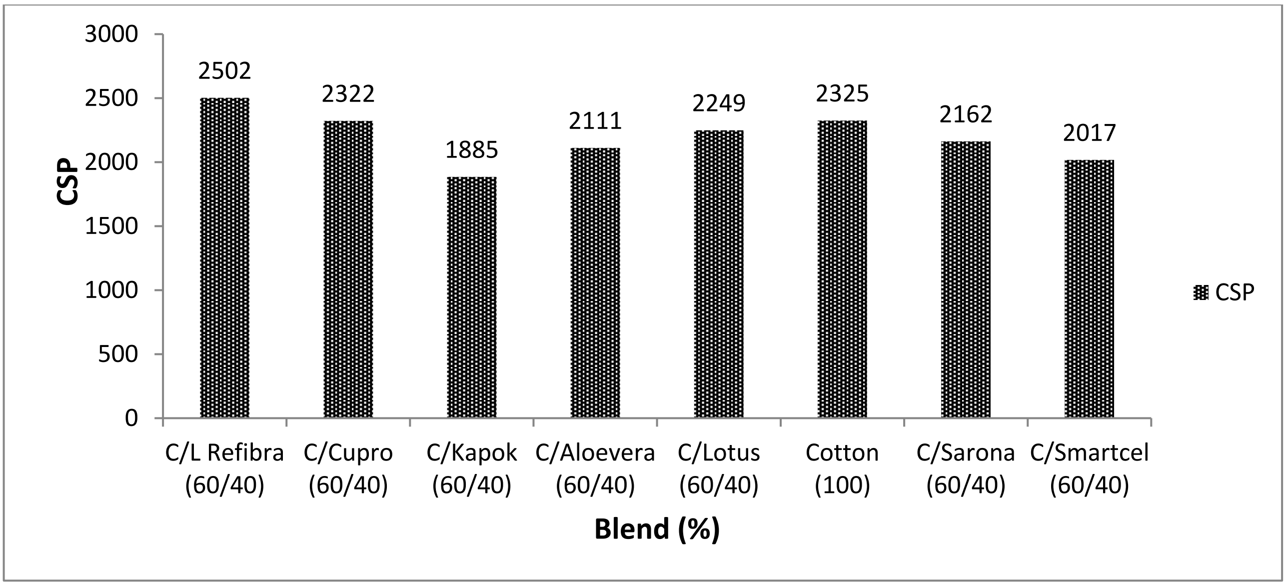

Fig. 3.1-Variation in count strength product with blend (%) for different fiber type.

3.2 Yarn Unevenness

The variation in the yarn unevenness with different blend (%) of all type of yarns given in the following figure 3.2 . It may be observed that Cotton/Kapok (60/40) yarns have higher yarn unevenness as compared to Cotton/Lenzing Refibra (60/40), Cotton/Cupro (60/40), Cotton/Aloevera (60/40), Cotton/Lotus (60/40), Cotton (100), Cotton/Sarona (60/40) and Cotton/Smartcel (60/40) yarns. The excellent performance of Cotton/Aloevira indicates that this fiber is highly uniform and consistent in length, mixing well into cotton to form an extremely uniform strand. Cotton/Lenzing Refibra mixes well in order to ensure evenness. Kapok fibers are extremely short and slippery so they cannot be drafted and twisted equally into the cotton matrix, resulting in enormous lumps and thinning areas. Lotus fibers although a novelty, seem hard to process into a uniform yarn compare to cotton. Sarona although tough, can have variable drafting characteristics than cotton. Smartcell, Cupro fibers could be non-uniform during spinning, resulting in greater U%. Cotton & Capok is a natural fiber with greater variability in length and fineness than regenerated fibers. As the cotton & Kapok fiber used in blend, this reduces the mean fiber length in the yarn, leading to weaker consolidation during spinning. The result is more pronounced drafting waves and higher mass irregularity [10].

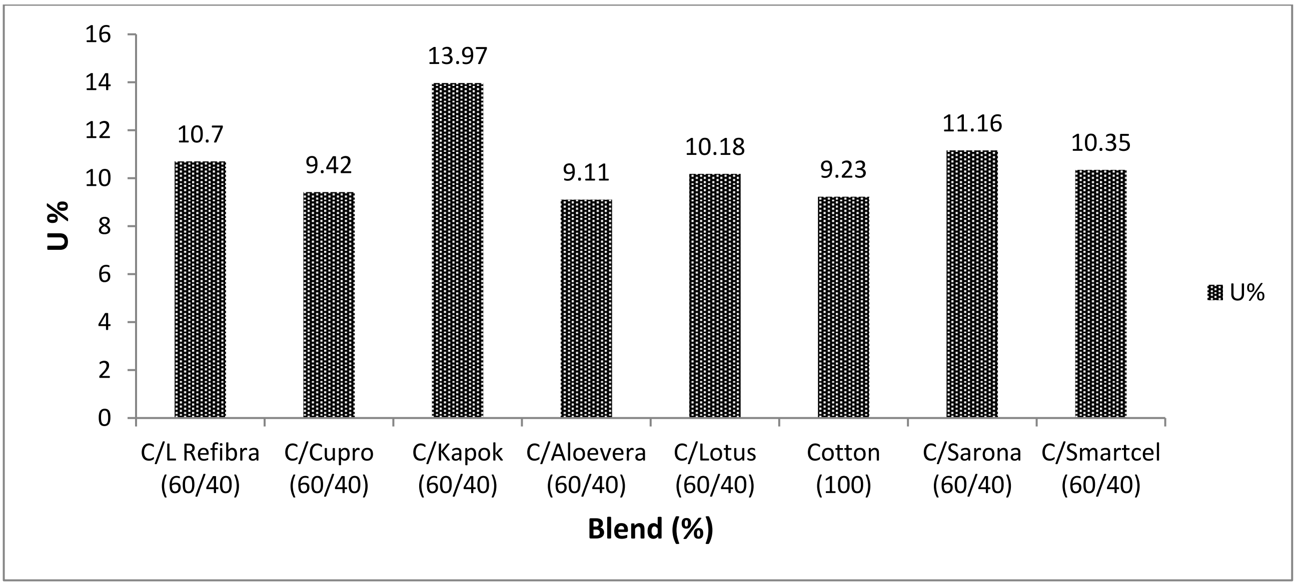

Fig. 3.2-Variation in yarn unevenness (%) with blend (%) for different fiber type.

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3.3 Imperfection Index

The variation in the imperfection index with different blend (%) of all type of yarns given in the following figure 3.3. Regenerated fibers exhibit superior uniformity in their longitudinal dimensions, contrasting with the inherent irregularity and twisted morphology of cotton fibers. Therefore, blended yarns with a higher regenerated fiber content possess a greater mean fiber length and a reduced population of short fibers. This promotes more effective fiber control during drafting, leading to superior association and orientation within the yarn structure. Cotton/Aloevera (60/40) blend have lowest Imperfection Index. Their high U% (evenness) indicates few thin or thick spots. 100% Cotton & Cotton/Allovera (60/40) yarns indicated excellent U% values, so they will likely have a very low Imperfection Index, as close to Cotton/Cupro as possible. Cotton/Sarona (60/40) yarns have a fairly low Imperfection Index, although possibly higher than the top four. Cotton/Cupro (60/40) yarns have slightly greater U% than cotton, and therefore we can anticipate a medium level of higher imperfections. Cotton/Sarona (60/40) yarns have high U% and low strength, suggesting a very large number of imperfections (thin spots, probably resulting in breaks). Cotton/Lotus (60/40) yarn have extremely high U% and extremely low strength, this mixture will have an extremely high Imperfection Index, with numerous thick places, thin places, and neps. Cotton/Kapok (60/40) yarns have highest Imperfection Index. The graph probably has a bar for Kapok that is orders of magnitude higher than the others. The yarn is so irregular and weak that it is basically made up of defects. As a result, an increased Kapok contribution directly elevates the total imperfection level in eco yarn [10].

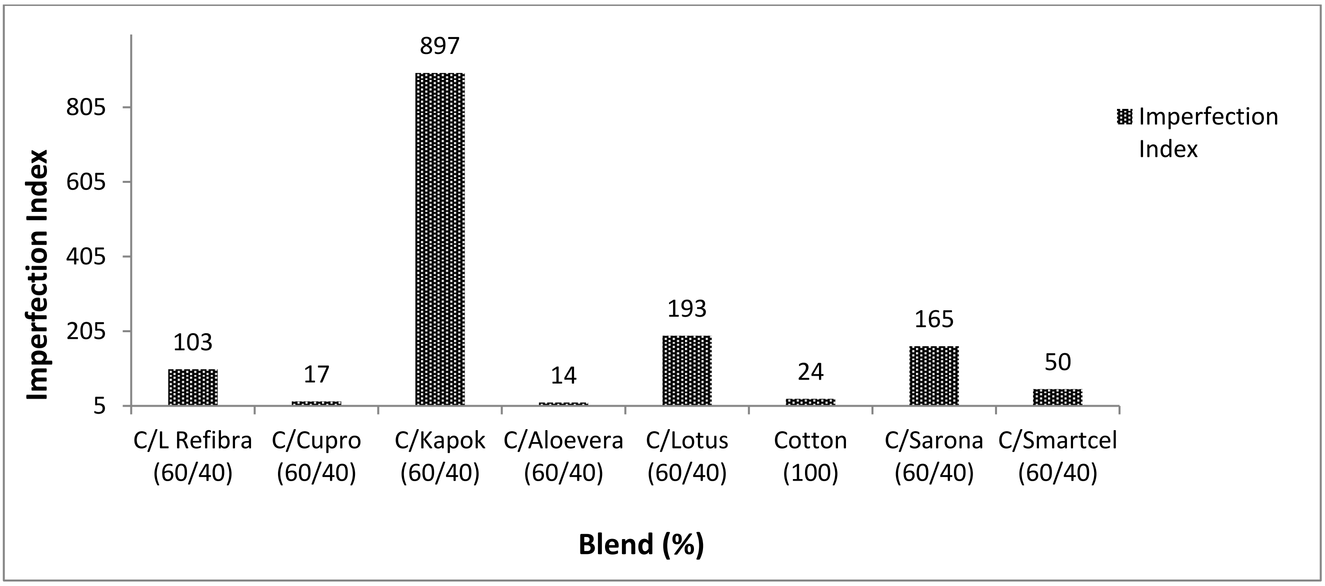

Fig. 3.3-Variation in imperfection index with blend (%) for different fiber type.

3.4 Hairiness

Cotton/Smartcel fibers have long staple fiber length and are extremely smooth and resistant. When spinning, these fibers break less and project from the yarn than short staple fibers. They wind beautifully around the yarn core, producing a very smooth surface lead to lowest hairiness in Cotton/Smartcel blend.

In spite of its low tenacity, Smartcel fibers exhibit high fiber cohesion and high flexural rigidity (they are stiffer). This indicates that they are less prone to brushing out of the yarn structure during process and abrasion, providing a relatively smooth yarn & slightly low hairiness in Cotton/Smartcel. Cotton is a medium-length staple fiber with moderate rigidity. In the spinning and later stages, fibers get broken or pulled out, leading to a relatively greater hairiness.

Cotton/Kapok blended yarns with highest hairiness. This finding most aptly describes the characteristics of the Kapok fiber. Although its length contributes to strength, the fact that it is very fine renders it highly pliable and susceptible to pushing out from the yarn body. Such fine fibers are readily teased out in the process of mechanical processing to yield a much fuzzier and hairier yarn surface.

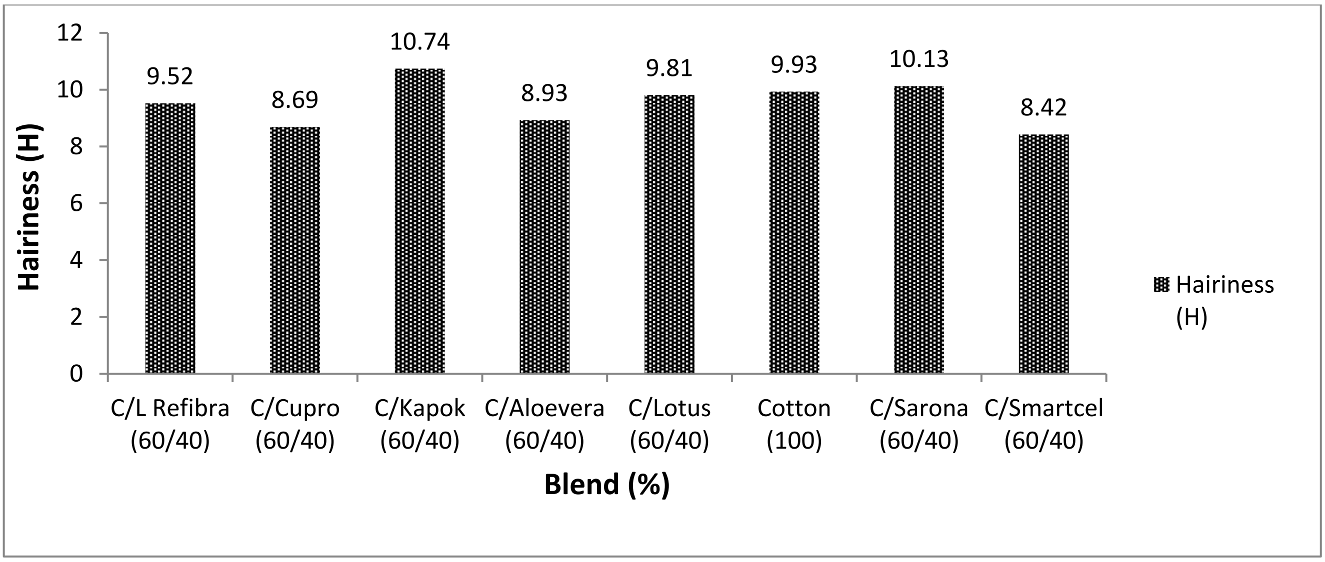

Fig. 3.4-Variation in hairiness with blend (%) for different fiber type.

3.5 Elongation

The variation in the elongation with different blend (%) of all type of yarns given in the following figure 3.5. The Cotton/Sarona (60/40) mixture possesses the greatest elongation by a very large margin at close to 6%. This reflects that it is the most elastic and stretchy yarn. Cotton 100%, Cotton/Kapok (60/40) mixtures possess the least elongation. Cotton of 100% pure form is renowned for having relatively low intrinsic stretch. Cotton/Smartcel and Cotton/Lenzing refibra exhibit a modest increase in elongation when compared to 100% pure cotton. Cotton/Cupro, Cotton/Aloevera, and Cotton/Lotus are the same as, or slightly better than, straight cotton, but they have lower elongation than Cotton/Sarona. Sarona is a nylon, and nylon is an elastomeric fiber known for years. It has very good stretch and recovery. Merging 40% nylon with cotton makes the yarn's elongation very much greater, making it considerably more flexible and resistant to breakage from sudden stress. Smartcel is frequently designed for performance, such as enhanced flexibility and longevity. Its modest elongation value illustrates this, revealing it to possess greater give than straight cotton. Cotton/Lenzing Refibra (presumably Lyocell or Rayon) also exceeds cotton slightly. These regenerated cellulose fibers may possess a smoother, more aligned fiber structure capable of sustaining more stretch prior to failure. Cotton/Kapok's virtually zero elongation is in harmony with its catastrophic failure in all other tests. It adds no beneficial mechanical characteristic. Cotton/Cupro, Cotton/Lotus, and Cotton/Aloevera are nature-based fibers that they all possess the same basic property as cotton which is low stretch. They do not add greatly to the elongation characteristic of the cotton base.

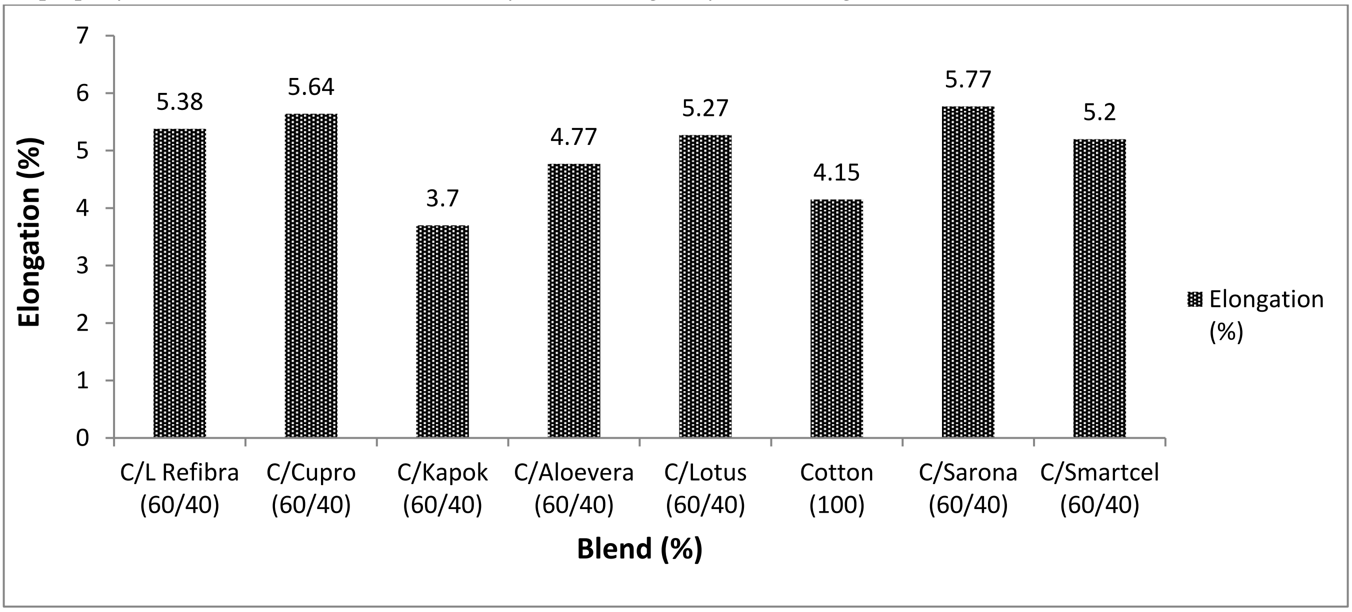

Fig. 3.5-Variation in elongation with blend (%) for different fiber type.

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3.6 Tenacity

The variation in the tenacity with different blend (%) of all type of yarns given in the following figure 3.6. Cupro (cuprammonium rayon) is a regenerated cellulose fiber, much like cotton. Its chemical similarity allows for excellent compatibility and bonding within the yarn structure. While cupro itself is less strong than cotton, its ability to form a cohesive matrix with the cotton fibers means stress is distributed more effectively than in blends with more dissimilar fibers. Sarona is a strong synthetic fiber, but its hydrophobic nature creates poor adhesion with hydrophilic cotton. This leads to inefficient stress transfer, explaining why it's not as strong as the cotton-cupro blend. Smartcell is a very strong regenerated cellulose fiber—often stronger than cotton when pure. However, in a blended yarn structure, the different fiber morphologies and stress-strain behaviors can lead to non-optimal load sharing, resulting in strength lower than 100% cotton but higher than blends with very weak fibers. Kapok is a hollow, buoyant fiber used historically for life preservers. It is very weak, brittle, and smooth, making it difficult to spin into yarns. Its inclusion at 40% drastically reduces the blend's strength as it cannot bear any significant load. Lotus and Aloevera fibers are novelty fibers prized for their luxury and cultural significance rather than their mechanical performance. They are typically weak, and difficult to process. Like kapok, they act as "fillers" that disrupt the continuous network of stronger cotton fibers, creating countless weak points and leading to very low overall tenacity.

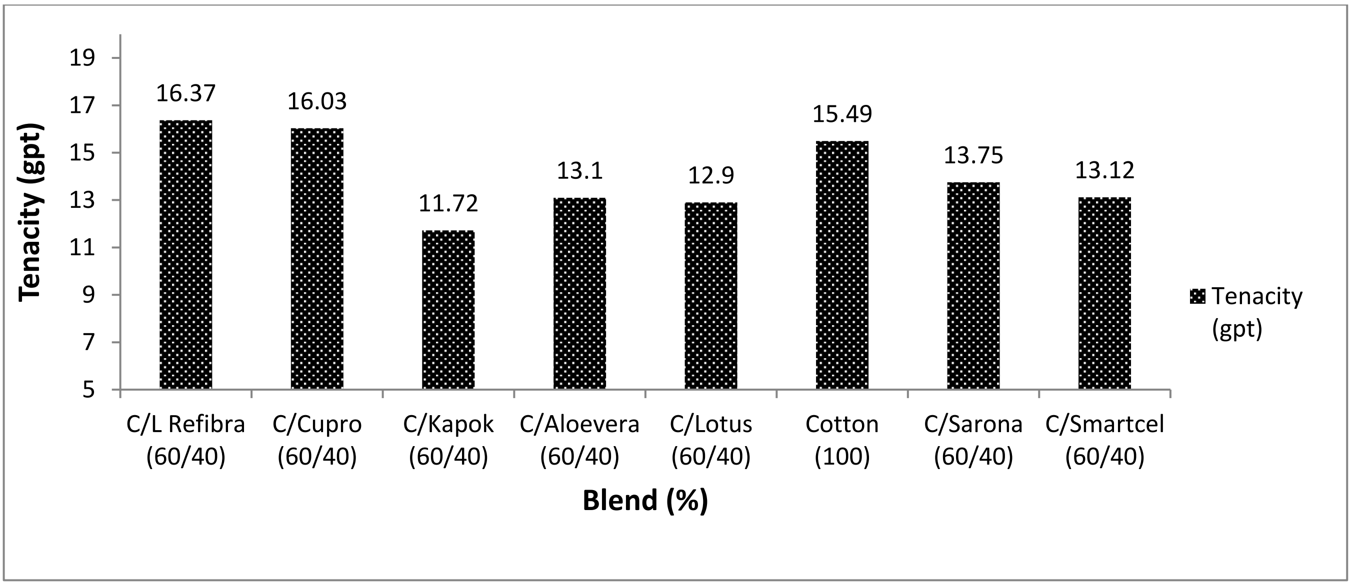

Fig. 3.6-Variation in Tenacity with blend (%) for different fiber type.

3.7 Coefficient of Friction

A properly spun 100% cotton yarn has a smooth surface. Cotton fibers possess a natural convolution (twist) that, when spun with a proper twist factor, can produce a coherent and dense yarn structure with few projecting fibers. This results in a low and uniform coefficient of friction.

The dataset shows a wide variation in coefficient of friction (μ) between tested 2/30 Ne yarn blends, from as low as 0.05 (100% Cotton, Cotton/Kapok) up to 0.18 (cotton/smartcel). Pure cotton and the Cotton/Kapok blend have lowest friction values ($\mu = 0.05$), but smartcel and Lotus blends both show significantly higher friction ($\mu = 0.18$ and 0.14 respectively). The majority of blends with other cellulosic fibers such as lenzing refibra, sarona and aloe vera fall between these extremes ($\mu = 0.06–0.12$). Blends containing some high-tech or specialty fibers (smartcel, lotus) have higher friction. Blends of natural/cellulosic fibers closely following 100% cotton have lower coefficients of friction, indicating comparable surface properties and fiber morphologies. Lotus ($\mu = 0.14$) and smartcel ($\mu = 0.18$), containing functional/biopolymer infusions, are consistent with higher μ, most probably from their micro structural surface heterogeneities and higher fiber-to-fiber surface area. lenzing refibra and sarona mixtures have middle values, reflecting moderate surface roughness change and lubricity change without drastic property

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alterations. Lower μ is usually associated with more even and more spinnable yarns, whereas increased μ enhances cohesion but may present difficulties in spinning and fabric development.

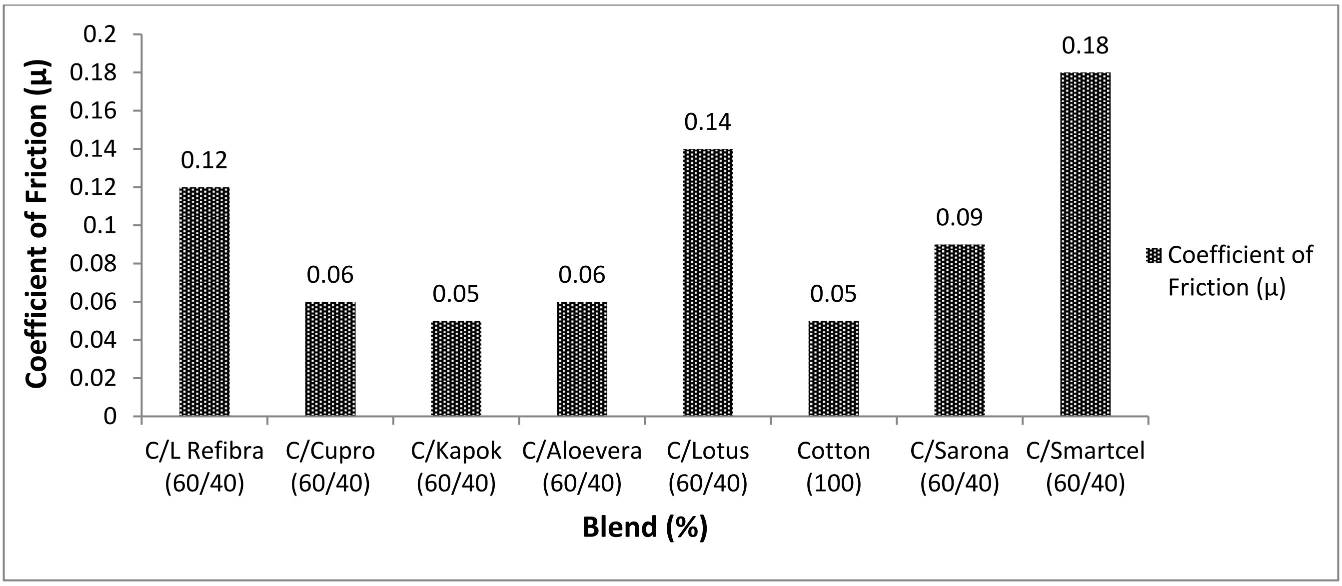

Fig. 3.7-Variation in coefficient of friction with blend (%) for different fiber type.

4 CONCLUSIONS

In this study, the physical characteristics of sustainable eco yarns made by combining cotton with various alternative fibers such as lotus, smartcel, kapok, refibra, pineapple, sarona and aloevera were comprehensively assessed. On the basis of detailed examination of all appended data sheets, such as performance data for different cotton-based fiber mixtures, the following strongly-supported conclusion determines the highest-performing fiber and gives a brief justification.

Cotton/Lenzing Refibra (60/40) has the best performance profile in general, as revealed by its properties.

- Highest CSP (2502): Indicates maximum yarn strength and integrity.
- High Tenacity (16.37): Is associated with superior durability and breaking strength.
- Balanced U% (10.7) and fair hairiness (9.52): Suggest good evenness and easy fly or pilling control.
- Fair IPI (103): Much better than Cotton/Kapok blend with very high IPI (897), showing fewer yarn defects.
- Reasonable Elongation (5.38): Facilitates adequate stretch and flexibility for textile application.
- Fair Friction Coefficient (μ = 0.12): A fine compromise between processing ease and fiber adhesion, reducing both slippage and machining problems.

Cotton/Cupro and 100% Cotton: Both have low friction (μ = 0.06, 0.05) and medium-to-high yarn strengths, but slightly lower CSP and tenacity compared to Refibra, with Cupro being best in evenness and few imperfections.

Cotton/Kapok: Very high IPI and low CSP (1885), with highest hairiness (10.74), suggesting great disadvantages for industrial processing and end-use strength despite lowest friction.

Cotton/Smartcel: Maximum friction (μ = 0.18), moderate strength, but acceptable tenacity with its performance lowered by higher friction and only moderate yarn characteristics.

Cotton/Lotus and Cotton/Sarona: Moderate results with moderate CSP, higher hairiness, and higher friction, resulting in less desirable processing and end yarn values.

Cotton/Lenzing Refibra (60/40) blend is the overall best for both quality and industrial processing:

• Provides the highest combined tenacity and CSP, guaranteeing strong, long-lasting yarn.

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• Maintains balanced friction characteristics for efficient manufacturing.

• It is good balance between evenness (U%), low hairiness, and low-to-moderate imperfection index (IPI).

• Provides added value by virtue of being eco-friendly and containing recycled material (a leading trend in international textile creativity and supply chain sustainability).

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