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Surface Friction Characteristics of Woven Fabrics with Nonconventional Fibers and their Blends

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ABSTRACT

The research work aimed to analyze the surface frictional characteristics of fabric made of different nonconventional fibers like lyocell, bamboo, micro polyester, micro lyocell, bamboo/charcoal, bamboo/cotton and their blends. The fibers were made as fabric in plain weave with different cover factors. The effect of fabric cover on the frictional characteristic was analyzed. The result reveals that the increase in cover factor gradually decreases the friction coefficient. With respect to the fiber type and frictional properties, it is found that, the least frictional coefficient value was noticed in the case of pure lyocell. The maximum frictional valued noted in the case of cotton and charcoal blends. The static and dynamic friction coefficient values of different fibers were statistically significant. The friction coefficient values are in the following order for static and dynamic friction respectively; Lyocell < Micro Lyocell = Micro Polyester < Bamboo < Polyester < Bamboo/Cotton < Bamboo / Charcoal and Micro Lyocell < Lyocell < Bamboo < Micro Polyester < Bamboo/Cotton < Polyester < Bamboo / Charcoal. The results also identified that the influence of blend proportion and fabric structure on the frictional properties were also highly significant ($p<0.05$) as like the fiber content. The plain woven fabric has lowest frictional coefficient values than twill structures. The frictional coefficient values of the fabric structures are in the order of Plain < 2/2 Twill < 1/3 Twill.

Keywords: Static and Dynamic friction, Nonconventional fibers, Fiber blends, Weave type, Cover factor

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1. INTRODUCTION

Frictional characteristics of woven fabrics can determine smoothness and softness values of the fabric. Fabric friction, which is defined as the resistance to motion, can be detected when a fabric is rubbed mechanically against itself or tactually between the finger and thumb. Friction is considered to be one property of cloth which has considerable importance in the fields of both technological and subjective assessment. Earlier investigators[1-3] have established empirical equations between the frictional force developed as a fabric moves over another and the normal load (pressure) acts over the fabric surfaces. It is important to assess the fabric friction quantitatively as well as the factors that may affect it. Objective measurement of the frictional properties of various fibers and fabrics helps in clear communication of the particular process.

The coefficient of friction is defined as the friction exerted between two layers of fabrics. Static coefficient of friction (μ) is the frictional coefficient exerted at a static condition whereas Dynamic coefficient of friction (μd) is the frictional coefficient exerted when the layers are in a relative movement with each other. The frictional characteristics of the woven fabric mainly depends on the type of fiber and the surface charactristics of the fiber. The dynamic coefficient of friction (μd) between two materials is usually defined as the ratio between the frictional force F and the applied normal load N[4]:

$$\mu = F/N \quad (1)$$

It is known that the friction of polymeric materials does not follow this law of Amontons[5]. Ramkumar *et al*[6,7], studied the frictional behavior of woven and nonwoven fabrics and found that for textiles the relationship between friction force and normal load can be expressed as shown below;

$$F/A = C(N/A)n \quad (2)$$

where F is the frictional force, N the normal load, A the apparent area of contact, C the friction parameter and n the friction index (non-dimensional). Any fabric that offers little frictional resistance to motion across its surface and possesses a low coefficient of friction is likely to be described as a smooth fabric. In view of the diverse nature of fabric surfaces and the fact that normal pressure (load) and frictional resistance are not always in direct proportion, the coefficient of friction alone may be insufficient for surface characterization and degrees of smoothness or roughness may also be important factors. Another factor influencing the friction of textiles is the sliding velocity. Hermann *et al*[8]., observed that the friction of fabrics tends to increase with increasing sliding velocity.

Behmann et al[9], reported a study on the perception of roughness and textile construction parameters by the friction coefficients. Okur et al[10], found that the frictional resistance of the fabrics knitted with carded yarns was higher than that of fabrics knitted with combed yarns. Protruding fibers on the fabric surface were the most important factor affecting fabric surface smoothness and frictional properties. Polyester fiber has higher coefficient of friction as compared to viscose. The fabric-to-metal surface and fabric-to-fabric frictional characteristics (in both warp and weft directions) of a series of fabrics containing 100% polyester, 100% viscose, and P/C & P/V blends with different blend proportions are also examined by Apurba Das et al[11]. In P/C and P/V blended fabrics, the frictional force increases as the cellulose fiber component increases, and the blended fabrics show higher fabric-to-fabric friction than 100% polyester or 100% viscose.

Apurba Das et al[12] analyzed the frictional characteristics of woven suiting and shirting fabrics with different blends, construction parameters and found that the fabric to metal friction is less sensitive to fabric morphology and rub direction, whereas the fabric to fabric friction is highly sensitive to the type of fiber, blend, yarn structure, fabric structure, crimp, compression etc. For all fabrics kinetic friction is always lower than static friction of different levels. Mário Lima et al[13], described novel patented laboratory equipment, which was studied, designed, and manufactured at the University of Minho, Portugal, based on a new method of accessing frictional coefficient of fabrics. The authors compared fabrics produced with a new generation of fibers, namely poly lactic acid (PLA) fiber and soya protein fiber (SPF) and confirmed that SPF is softer than PLA. The relationships between the coefficient of friction and the fabric smoothness and handle are studied by some researchers[14].

In this work, fabrics made from non-conventional fibers like lyocell, bamboo and bamboo charcoal fibers and their blends with cotton and polyester were analyzed for the frictional behavior. The fabrics were used for the analysis based on their wide importance in the area of functional and health care applications. The influence of different fiber and their blends on the frictional coefficient were analyzed. The effect of fabric cover factor and weave type on the frictional behavior of the fabrics were also mentioned.

2. MATERIALS AND METHODS

Lyocell, micro lyocell, Bamboo, Bamboo/ cotton, bamboo charcoal, polyester, micro polyester fibers are used to produce fabrics in pure form and also in blended form. Lyocell/ polyester blended yarns are produced in four proportions such as 100% lyocell, 85:15 and 70:30 lyocell / polyester and 100% polyester. Similarly blended fabrics are produced from micro lyocell/micro polyester and from each of these blended yarns produced, three fabric samples with plain weave, 2/2 twill weave and 1/3 twill weave were produced with a cover factor of 24. The list of fabric samples produced and the fabric parameters are given in the Table 1.

Table 1. List of Fabric Samples

Fiber	Yarn count (Ne)	Weave	Ends/cm	Picks/cm	Fabric weight (g/m^2)	Fabric thickness (mm)
Bamboo	29.6	Plain	40	35	148	0.42
		2/2 Twill	40	32	141	0.52
		1/3 Twill	40	35	147	0.51
Bamboo/cotton	29.8	Plain	39	35	147	0.46
		2/2 Twill	40	88	147	0.57
		1/3 Twill	39	86	144	0.65
Bamboo charcoal	29.5	Plain	36	31	136	0.35
		2/2 Twill	37	34	136	0.37
		1/3 Twill	36	34	128	0.37
100% Lyocell	30.4	Plain	36	31	136	0.35
		2/2 Twill	37	30	152	0.37
		1/3 Twill	36	30	149	0.39
85:15 Lyocell/ Polyester	29.3	Plain	37	27	151	0.40
		2/2 Twill	36	25	170	0.41
		1/3 Twill	37	30	175	0.46

70:30 Lyocell/ Polyester	30.7	Plain	38	34	173	0.50
		2/2 Twill	37	26	188	0.50
		1/3 Twill	37	34	198	0.53
100% Polyester	30.7	Plain	37	34	195	0.55
		2/2 Twill	35	39	172	0.42
		1/3 Twill	35	39	173	0.45
100% Micro Lyocell	30.2	Plain	35	38	175	0.51
		2/2 Twill	35	39	161	0.45
		1/3 Twill	35	39	163	0.52
85:15 Micro Lyocell/ Micro Polyester	29.8	Plain	35	38	165	0.50
		2/2 Twill	34	39	152	0.42
		1/3 Twill	36	39	154	0.50
70:30 Micro Lyocell/ Micro Polyester	29.6	Plain	36	38	158	0.52
		2/2 Twill	35	38	133	0.45
		1/3 Twill	36	39	129	0.50
100% Micro Polyester	29.7	Plain	35	39	127	0.52
		2/2 Twill	35	39	172	0.42
		1/3 Twill	35	39	173	0.45

2.1 Measurement of Fabric Frictional Factor

Fabric frictional coefficient was measured as per ASTM D1894 standard using a computer aided friction tester, exclusively for characterizing friction in fibers, sheets of yarn, fabrics, nonwovens, polymeric films, composites and other technical textiles. Fabric friction is determined by measuring the force that opposes relative motion between two fabric surfaces in contact. It is the resistance encountered when two bodies in contact are allowed to slide. The instrument with the aid of online computer and application software, measures fabric-to-fabric friction and determines various frictional parameters, like the Static Frictional Force which is the maximum force required to cause sliding between the two fabric assemblies; the Dynamic Frictional Force, which is the average force required to cause continued sliding between two fabrics, and also records the friction profile. The instrument has three major units, namely Control unit, Drive unit, and Clamping unit. The schematic representation of the system is shown below in Figure 1.

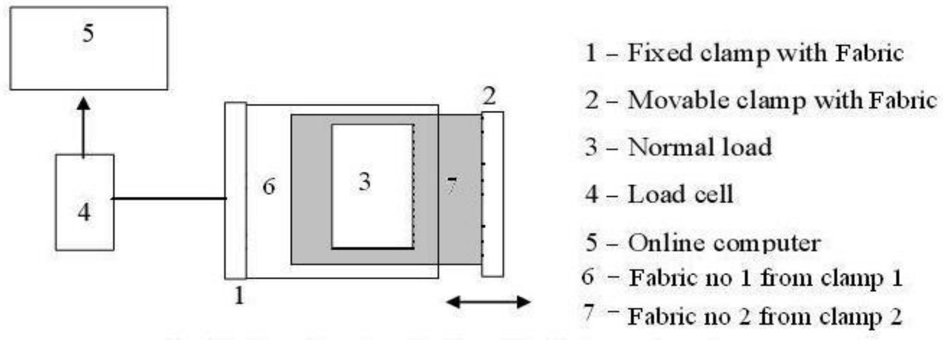

Figure 1. Schematic representation of the Instrument

Rectangular fabric samples of 5cm x2.5 cm were prepared and unraveled at edges to correct the grain in the warp and weft direction. The fabric samples are clamped in such a way that the fabric samples lie one over the other with the normal load of 100g placed above them. The clamp starts to move at a speed of 100 mm/min with a total displacement of 12mm. The static and dynamic frictional factors were recorded using a computer integrated with the testing instrument for ten samples in each category of fabric.

2.2 ANOVA Analysis

To prove the difference in surface roughness between different fibers, weave types and cover factors statistically ANOVA analysis were performed and the results interpreted.

3. RESULTS AND DISCUSSIONS

Fabric friction, which is defined as the resistance to motion, can be detected when a fabric is rubbed mechanically against itself or tactually between the finger and thumb. Friction is considered to be one property of cloth which has considerable importance, when skin is in close contact with the fabric. The ratio of frictional force (F) to normal load (N) is calculated and denoted as (F/N). From the tables, it can be seen that the static frictional ratio value is represented as (F/N)s and the kinetic frictional ratio value as (F/N)d. The static frictional force is higher than the kinetic frictional force for all the fabrics and the (F/N) values reduces with the increase in the normal pressure. The relationship between the frictional force and normal load is found to be logarithmic, as was found by Wilson[14]. The relationship is

$$(F/A) = k\,(N/A)^{n} \quad \text{or,} \quad \log (F/A) = \log k + n \log (N/A) \;\ldots.\; (3)$$

where, A is the area of contact, k is the friction parameter and n is the friction index.

When two fabrics are in contact, they may interact structurally, which contributes to high friction. When the fabric is in contact with another fabric, the surface fibers penetrate into the domain of the other fibers of the contacting fabric, and form a loose inter-fabric structure. The (F/N) ratio represents the energy lost in breaking this loose structure, while resistance comes from the adhesion at contact points of fibers and the bending of fibers in moving fabric surface. The frictional profile is plotted between displacement in mm and the force required to pull the fabric in grams. The inclined portion of the curve between 0.06mm to 1.6mm depicts the force required to pull the fabric from static condition which reaches its maximum value between 0.06 mm to 1.6 mm of displacement. The linear portion of the curve denotes the force required to keep the fabric moving which is denoted by the dynamic force. In all the friction profiles, the pulling force reduces as the fabric is dragged beyond 2.4mm. Frictional profiles of fabric sample were represented in Figure 2.

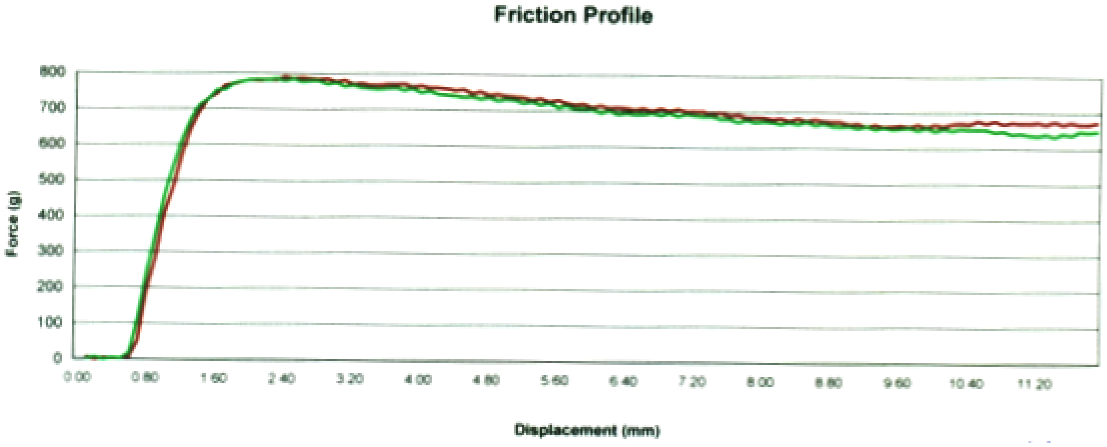

Figure 2. Frictional profile of fabric samples

3.1 Influence of Fabric cover factor on the frictional characteristics

Some of the comfort and surface properties like air permeability, water vapor permeability, thermal conductivity and frictional coefficient of a fabric depend on the fabric cover factor. To predict the effect of fabric cover factor on frictional properties, lyocell fabrics were woven with four different cover factors and analyzed for their frictional properties. As lyocell is the major component of all the fabrics developed, fabrics were produced using lyocell yarns, with cover factors such as 20, 22, 24 and 26 by varying the ends per inch and picks per inch and the fabrics produced were analyzed for their parameters and frictional properties. The test results are shown in the Table 2 and Figure 3.

Table 2. Fabric Parameters of lyocell fabrics with different cover factors

Cover factor	**Ends/cm x picks/cm**	**Thickness (mm)**	**Strength(kgf)**		**Elongation (%)**		**Frictional Factor**	
			Warp	weft	Warp	weft	Static	Dynamic
26	50x35	0.25	00	95	23.95	15.41	0.62	0.59
24	40x35	0.21	10	90	18.75	13.54	0.67	0.60
2	35x28	0.20	10	75	10.4	13.54	0.71	0.62
0	30x25	0.19	5	80	9.34	10.41	0.82	0.73

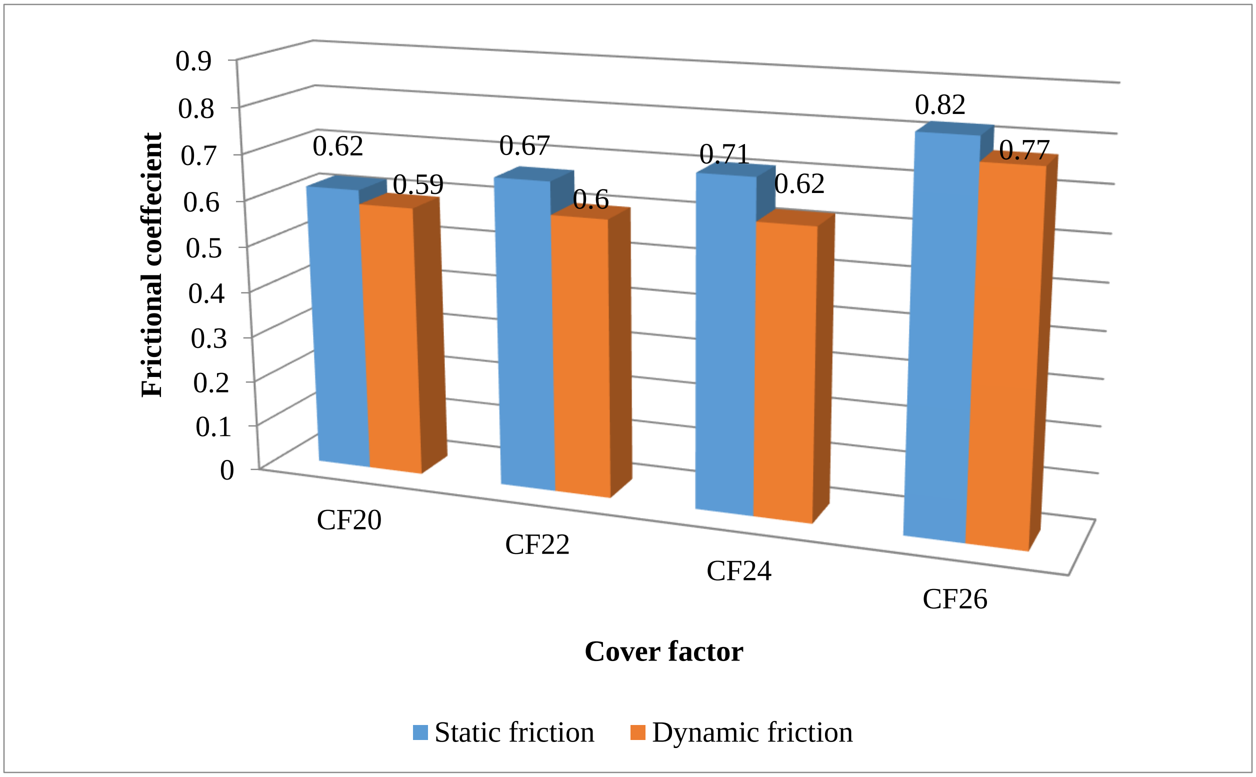

Figure 3. Effect of cover factor on the frictional properties of fabrics

This observation shows that fabric surface roughness is significantly affected by the fabric warp and weft yarn density. At low yarn density the loose structure of the weave causes the surface roughness to gradually increase. In general it can generally be seen that increase in weft setting causes decrease in fabric friction for all the weave types and this tendency is similar for static and dynamic friction. Also this result is in accordance with the previous research[16].

The relatively loose structure of weaves, especially at low yarn density, causes an increase in fabric friction. Increasing yarn inter-sections in weave unit provides to get the yarns closer to each other in contact points and this may cause decrease in roughness values. Out of all the roughness results of cotton fabrics are examined by Vildan sulara et al [17]. It is revealed that the smoothest fabric surface is obtained for the highest setting value for each weave type of the cotton fabrics. Backer and Tanenhaus[18] postulated that a large area of contact between the fabric and abradant would allow a better distribution of abrasive stresses, thus decreasing the localized load at any one fiber point. This would decrease frictional wear, surface cutting, fiber plucking, slippage and tensile fatigue.

An interesting result by Ajayi[19], showed that the increase in fabric sett decreased the projection of yarn knuckles above the plane of the fabric surface (crown height). This resulted in a more regular, compact, and smoother fabric surface. The researcher also mentioned that an increase in the yarn crimp as the consolidation of weft yarns increased, the magnitude of the yarn crown height decreased consistently. Thus the reduction in the crown height may be due to a decrease in the modular length of warp yarns[20, 21.] Further, Ajayi and Elder[22] mentioned that the yarn spacing is another major reason for the fabric surface friction variation. They have stated that an increase in yarn diameter for example, as the density of weft sett was increased, migration of yarns occurred and the spacing between warp yarns increased. In other case, when the warp yarn spacing remained unaltered as the weft yam linear density increased, there is a slight decrease in weft yarn spacing noted. In summary, with the support of abovementioned litterateurs, the changes in the cover factor, result in significant changes in surface geometry such as yarn crimp, spacing, crown height and fabric balance. The resultant changes in surface topography alter the resistance to motion and surface smoothness.

3.2 Influence of type of fiber on the frictional characteristics of fabrics

To analyze the effect of fiber type on the frictional characteristics, fabrics were produced from different fibers such as lyocell, bamboo, bamboo cotton, bamboo charcoal, polyester and micro polyester fibers with same plain weave structure and fabric cover factor of 24.

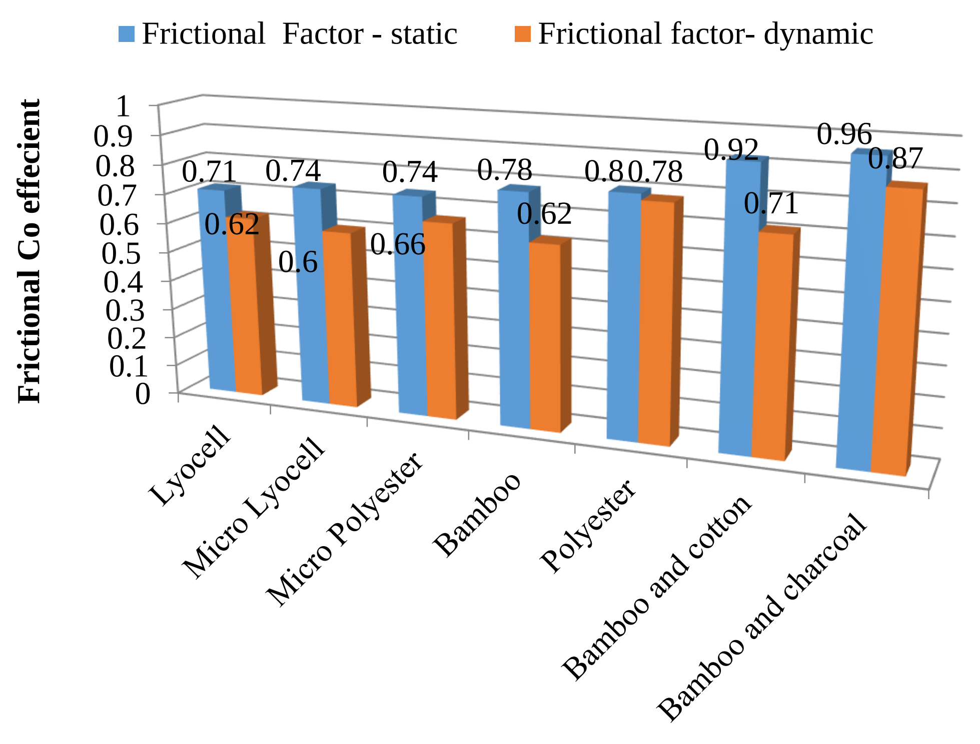

Figure 4. Influence of fiber type on the frictional properties of fabric

Figure 4 shows that the friction values of the lyocell fiber is found to be much lower than all other fiber in both static and dynamic case. The order of the static friction level found to be as follows: Lyocell < Micro Lyocell = Micro Polyester < Bamboo < Polyester < Bamboo/Cotton < Bamboo / Charcoal. The Dynamic friction vales are in the order of Micro Lyocell < Lyocell < Bamboo < Micro Polyester < Bamboo/Cotton < Polyester < Bamboo / Charcoal. Fiber cross sectional shape provides an area of link between two fiber surfaces, which is directly proportional to the fiber friction. Smooth cross sectional area of the fiber reduces friction where as edges produce friction. Cotton has maximum friction due to convolution (natural crimp) and has more static and kinetic forces than other fibers. In addition, the data reveal that cotton fabrics have more static and kinetic forces than polyester fabrics in all environmental conditions[23] The cross sectional view and the surface structure of lyocell, cotton and polyester fabrics is shown in the Figure 5.

Cotton **lyocell** **polyester**

Figure 5. Cross section of Cotton, Lyocell and Polyester Fibers

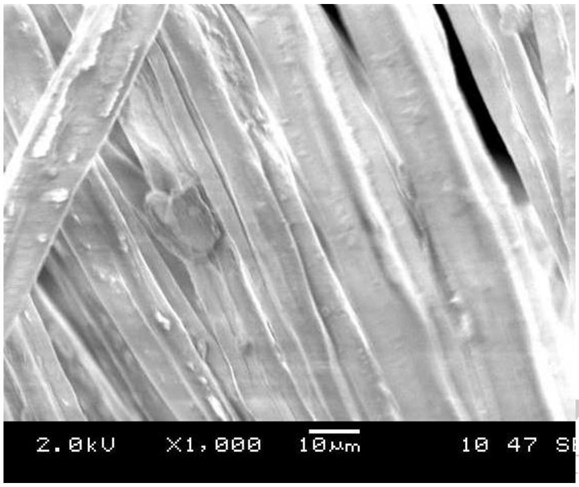

Figure 6. SEM image of Bamboo charcoal fibers

Lyocell fiber has an extremely smooth surface and feels soft and pleasant on the skin. Among all fibers tested, lyocell fiber exhibits very low frictional factor (both dynamic and static) due to its smooth surface. The cotton fiber has its natural crimp or convolution which increases the friction of the fiber. The combination of a smooth fiber surface and excellent moisture absorption of lyocell creates a positive environment for healthy skin, making lyocell ideal even for anyone with sensitive skin.

The Bamboo charcoal yarn selected for this research is polyester fiber based Bamboo charcoal yarn produced from polyester master batch by imbuing bamboo charcoal content of about 50%. The SEM image of Bamboo charcoal fiber (Figure 6) shows striations along the length of the fiber and presence of small particles of bamboo charcoal powder embedded in to the fiber surface. The Bamboo charcoal and bamboo cotton fabrics have higher frictional coeffecient compared to the remaining fabrics. Bamboo charcoal fabrics have higher frictional coeffecient due to the presence of bamboo charcoal particles which imparts slight roughness to the yarn.

Bamboo cotton blended fabric has higher F/N values than lyocell fabrics due to the fact that in the presence of cotton component, the yarn becomes comparatively fuzzier. These surface fibers will offer more resistance to the motion. The spaces between threads will also get covered by these surface fibers, so the real area of contact will be more which also results in higher friction.

100% polyester shows lower (F/N) values than that of cotton-blended fabrics, and as the proportion of cotton increases, the (F/N) becomes higher. As the surface of the 100% polyester is less populated with surface hairs, the resistance due to the formation of the loose structure at the interface of the two moving surfaces is less[11].

3.3 Frictional behavior of Lyocell/ Polyester blended Fabrics

To analyze the effect of blend proportion on frictional properties, fabrics were produced from lyocell and polyester blends and also from micro lyocell, micro polyester blends by varying the blend proportion as 100% lyocell, 70:30 lyocell/polyester, 85:15 lyocell/polyester and 100% polyester. Similarly blended fabrics were produced from micro lyocell and micro polyester. The static and dynamic frictional properties of all the fabrics produced were given in the Figure 7. It can be observed that the lyocell rich fabrics have lower frictional factor. As the surface of the 100% lyocell fabrics have very smooth surface, the resistance due to the formation of the loose structure at the interface of the two moving surfaces is less. When polyester is blended with lyocell, it offers higher friction which may be due the lower moisture content. The fiber with higher moisture content absorbs more moisture in it and therefore, the absorbed water layer behaves as a lubricant for further absorption of water molecules. This leads to the decline of surface adhesion and hence frictional surface[24, 25].

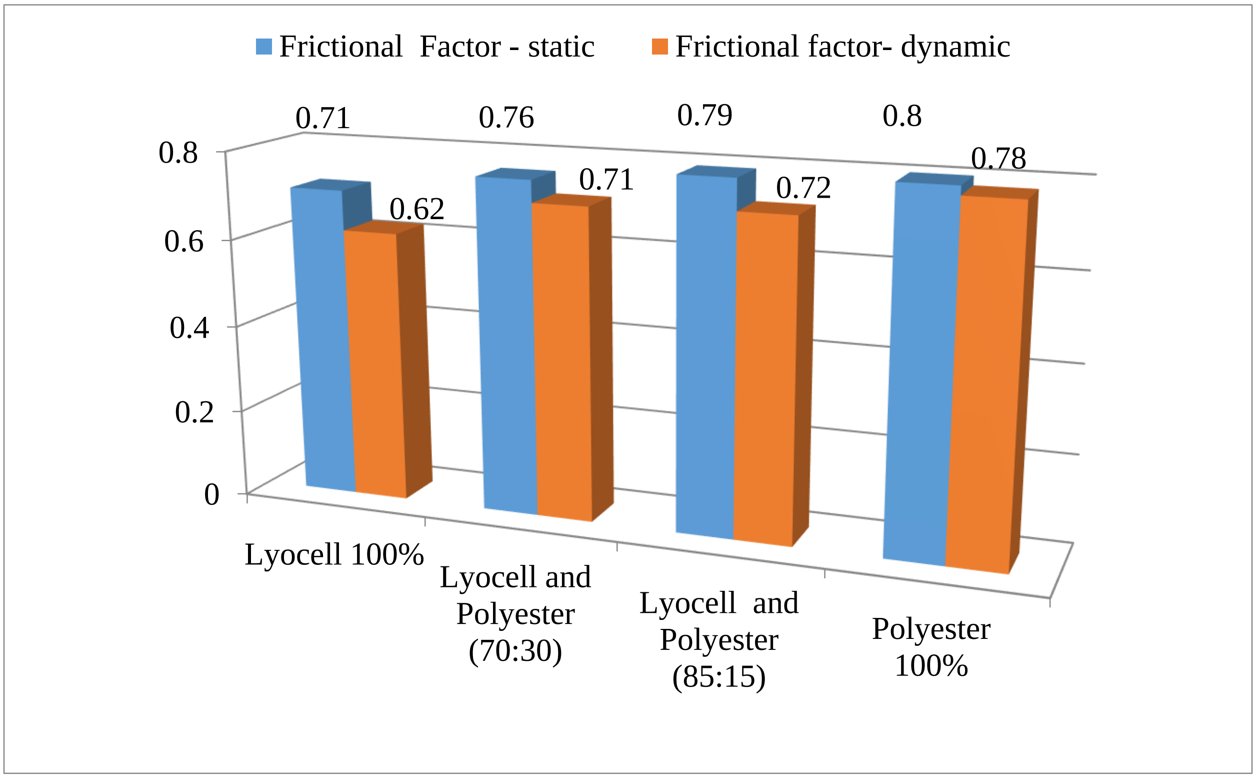

Figure 7. Frictional Behavior of Lyocell / Polyester Blended Fabrics

3.4 Frictional Behavior of Micro Lyocell/ Micro Polyester Blended Fabrics

The static and dynamic frictional characteristics of micro lyocell/micro polyester blended woven fabrics are given in the Figure 8.From the Figure 8 it is observed that as the micro polyester content in the fabric increases, the frictional factor decreases. This may be attributed to the lower specific density of micro polyester fibers. Due to lower specific density of these fibers, more number of fibers will be packed in a given count of yarn. Due to the higher packing density of fibers in the yarn, the yarn is more uniform and bulkier than micro lyocell yarn of equal count. Hence micro polyester fiber offers very less crests and troughs than micro lyocell fabrics leading to reduced frictional factor.

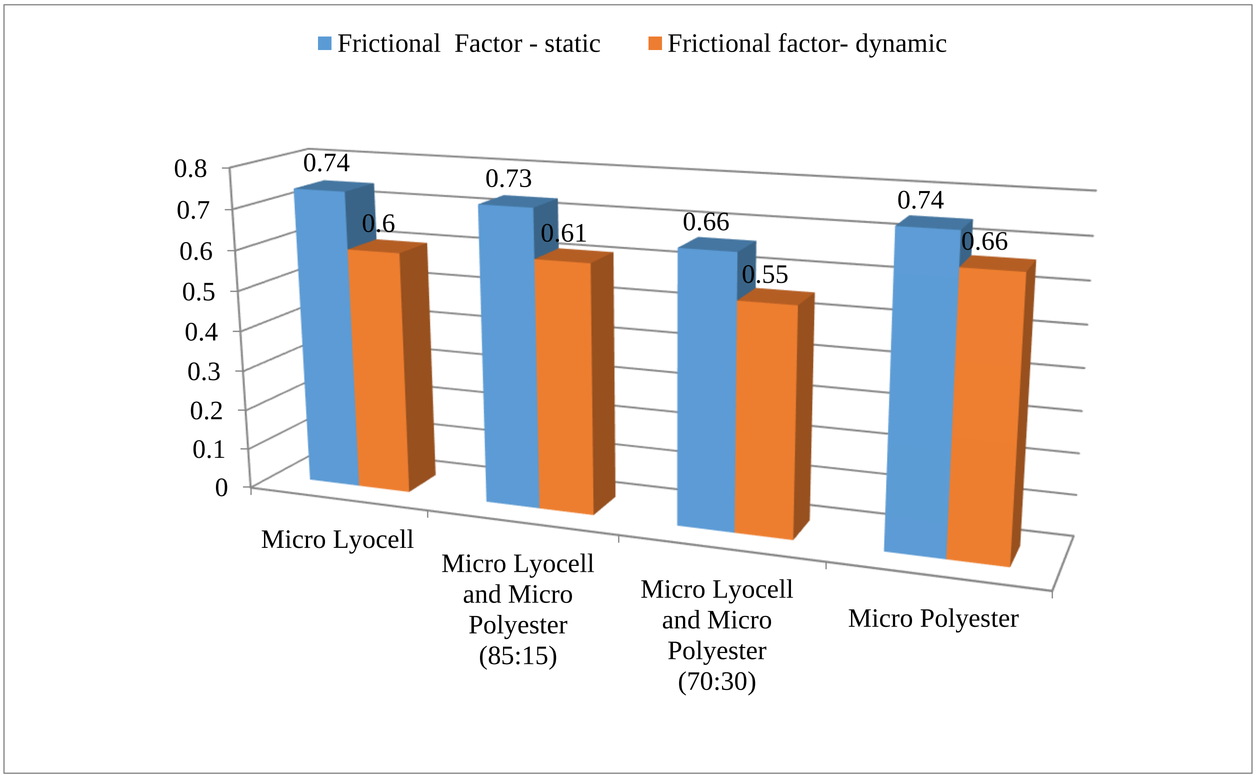

Figure 8. Frictional Factor of Micro Lyocell/ Micro polyester Blended Fabrics

3.5 Influence of type of weave on the frictional characteristics of fabrics

Figure 9 and 10 below shows the effect of weave on the frictional properties of the fabrics. When two fabrics are in contact they may interact structurally, which contributes to high friction. When the fabric is in contact with another fabric, the surface fibers penetrate into the domain of the other fibers of the contacting fabric, and form a loose inter-fabric structure. The (F/N) ratio represents the energy lost in breaking this loose structure, while resistance comes from the adhesion at contact points of fibers and the bending of fibers in the moving fabric surface. As the surface of the lyocell, bamboo and 100% polyester is less populated with surface hairs, the resistance due to the formation of the loose structure at the interface of the two moving surfaces is less.

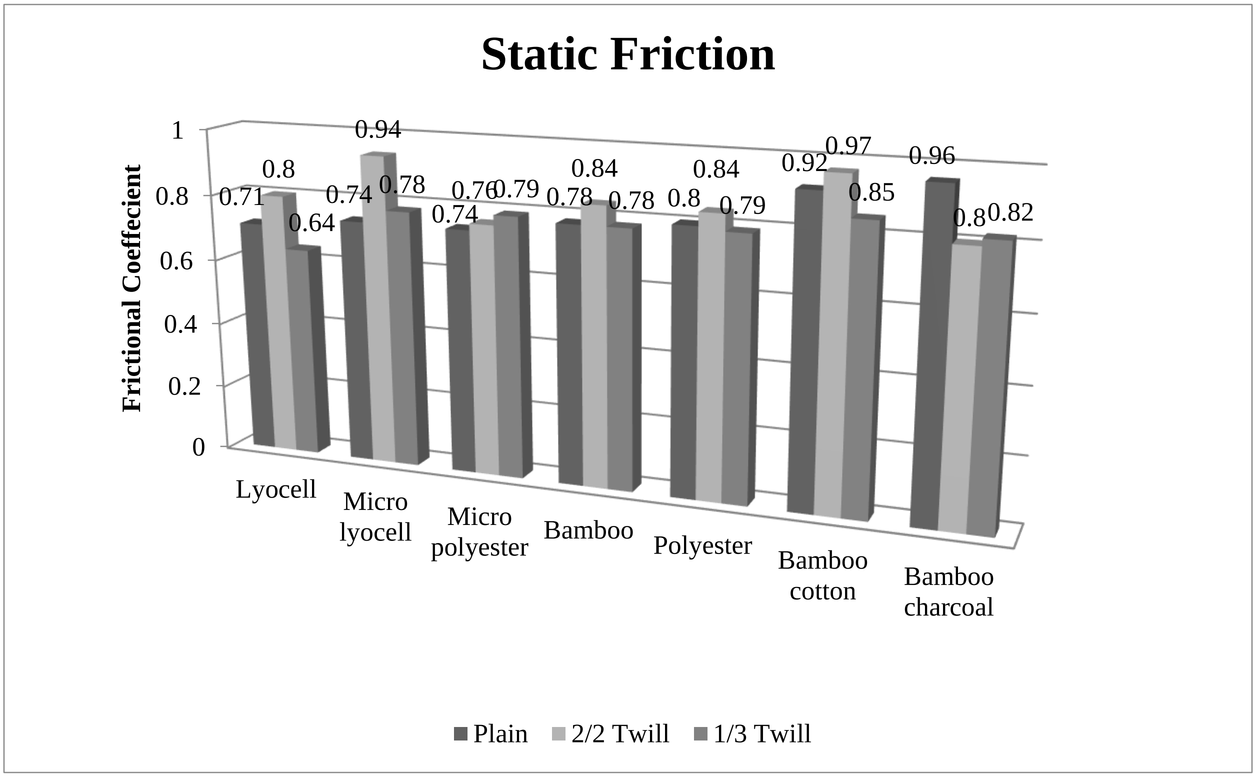

Figure 9. Effect of weave on the static friction of the fabrics

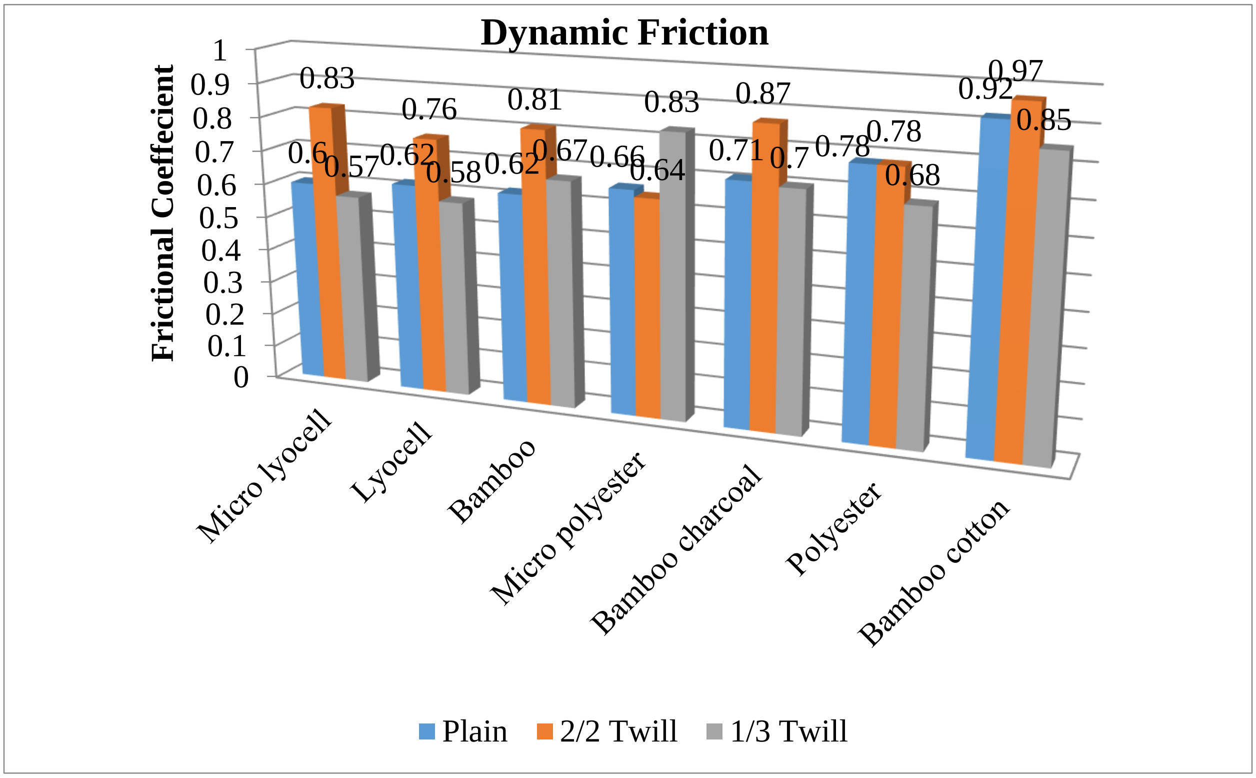

Figure 10. Effect of weave on the dynamic friction of the fabrics

This observation shows that fabric surface roughness is significantly affected by the fabric weave and weft yarn density. Plain woven fabrics exhibit lower friction which may be due to compactness of weave. 1/3 twill weave has higher friction than the plain and 2/2 twill fabrics. The relatively loose structure of 1/3 twill weave causes an increase in fabric friction. The gaps between the weft yarns increased as the weave changed from plain to twill, giving very high and very low peaks on the fabric surface, which in turn increased surface roughness.

Plain weaves provide the best fiber binding for flat and multidirectional abrasion. As a result of their simple structure plain weave fabrics were more balanced than either, 1/3 or 2/2 twill fabrics and the fabric balance gradually decreased with the increasing presence of yarn floats in the twill. Balanced yarn size and crimp give equal exposure of warp and filling yarn at the fabric surface.

The high surface roughness of twill weaves is at first sight surprising in view of their characteristically high light reflection and glossy appearance. The very high surface roughness values obtained indicates that the expected close packing of weft yarns was not maintained in the twill weave. The gaps between the weft yarns increased as the weave changed from plain to twill, giving very high and very low peaks on the fabric surface, which in turn increased surface roughness[26]. In weft dominated twill weave, as the weft yarn is coarser and the fabric is weft yarn dominated, it offers higher contact area and has shown higher frictional force. Warp dominated fabrics has shown lesser F/N values. Since float length is high, in a unit area, the number of cross over or interlocking points are less, resulting in lesser F/N values. Synthetic fabrics have shown lesser F/N value because of smooth surface. These results are in line with thin findings of Witold Zurek et al. [27] Twill weave provide adequate yarn mobility while reaping the advantages of weaving with higher thread counts than is possible with plain weaves. Further, longer float lengths in twill weaves are more vulnerable to plucking and snagging of fibers and the entire yarn[28]. During the change in fabric structure, in general alters the major physical factors like yarn crimp, yarn spacing and fabric crown height, which majorly contributes the fabrics frictional properties[20].

The ANOVA analysis results reveals that the influence of cover factor on the surface roughness is significant ($p<0.05$), a p values of 0.0058 noted. In the case of fiber content on the frictional co efficient the p value of 0.03 noted. Which supports the change in fiber type also influences the surface friction of fabric with same cover factor and same weave structure type. Further, study confirms that the changes in blend ratio both lyocell/polyster and micro lyocell and micro polyester blends affects the surface friction significantly. The effect on weave structure on the fabric friction is high and the significant p value of static and dynamic friction is 0.02 & 0.03 respectively.

4. Conclusions

Fabrics were produced from different fibers such as lyocell, bamboo, bamboo cotton, bamboo charcoal, polyester and micro polyester fibers and analyzed for frictional factor. The results of the experiments were summarized as follows:

- The increase in the fabric cover factor considerably reduces the frictional properties of the fabric. This behavior is attributed with the increase in more number of binding points and the surface uniformity of the tightly woven fabric with high cover factor
- The influences of fiber content on the frictional characteristics are highly significant. The lyocell fabric has the lowest friction coefficient and the fabric with cotton blends and bamboo charcoal blends possess high friction coefficient. The effect of different fiber blend ratio also has considerable impact on the static and dynamic friction of the fabric.
- The fabric structure with high amount of float has higher amount of frictional coefficient then the fabric with lower thread float. The plain woven fabric has

very less friction coefficient and the maximum value noted in the case of 1/3 twill.

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