A STUDY ON FRICTIONAL CHARACTERISTICS OF WOVEN FABRICS

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Abstract

We have examined 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. It has been observed that the normal load and the frictional force follow a logarithmic relationship for all the fabrics. The nature of fabric friction is characterised by different parameters such as the F/N ratio, and the values of n, k and k/n. Fabric-to-metal friction is found to be less sensitive to fabric morphology and rubbing direction, whereas fabric-to-fabric friction is highly sensitive to these factors. Fabric friction has been affected by many factors such as the type of fibre, type of blend, blend proportion, yarn structure, fabric structure, crimp and crimp height, compressibility, etc. In P/C and P/V blended fabrics, the frictional force increases as the cellulose fibre component increases.

Key words:

Cotton, polyester, viscose, blends cotton/polyester, blends polyester/viscose, fabric, static friction, kinetic friction

Introduction

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. Regarding the field of technology, friction is associated with the cutting of fabric multilayer and the separation of the fabrics in garment industries, and the friction of garments on other garments, upholstery and press covers. Earlier studies [1-12] have dealt with the various aspects of fabric friction.

Subjective assessment, which specifies the fabric handle, is undoubtedly influenced by the static and dynamic friction between the cloth surface and the thumb or finger, although other properties such as flexibility, thickness, shear etc. are also involved in the assessment. The friction of a fabric on itself or on another fabric has a significant effect on fabric performance features such as abrasion, wear and shrinkage, as well as on the user's tactile comfort. This sensation is primarily related to mechanical interaction between the clothing material and the human body. The human finger is a sensitive instrument capable of detecting small differences in the frictional behaviour of fabrics. The results of hand tests are expressed in subjective terms such as 'clingy', 'greasy', 'mushy', 'oily', 'rough', 'scratchy', 'sheer', 'sticky', 'waxy' etc., depending upon the sense of touch.

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 fabrics helps in clear communication and the optimisation of a particular process. It has been suggested that the relationship between human subjective assessment and objective measurement of the properties might be expressed as a linear function on a logarithmic scale.

Though fabric friction has gained much significance, there is no suitable instrument in the textile industry to measure fabric friction. Kawabata developed the KES-FB4 for the measurement of surface friction and the surface roughness of the fabrics. This instrument is however not available to all due to its very high cost. Most researchers have used the Instron tensile tester with some attachments to measure the inter-fabric or fabric-to-metal friction. In the present study, wide varieties of fabrics have been examined for their frictional and surface roughness characteristics on a locally designed and developed instrument.

The instrument

The schematic diagram of the instrument for measuring the frictional and surface roughness characteristics of the fabrics is shown in Figure 1. The instrument is meant for measuring fabric-to-fabric and fabric-to-metal friction and the surface roughness of the fabric. The fabric friction can be measured at different normal loads, at different speeds and under different fabric tensions. The traverse of the stroke can be adjusted. The instrument consists of three measuring devices, namely a load cell, a Linear Variable Differential Transformer (LVDT) and an encoder. The load cell measures the frictional pull on the upper surface by the moving lower surface; the LVDT measures the surface roughness, which is the vertical displacement of the probe in the fabric plane, and the encoder measures the distance travelled and the speed of the plate on which the fabric is mounted.

The instrument consists of a horizontal platform. The fabric to be tested is placed on this without any creases. This fabric can be kept under different tension by changing the tensioning weight. This platform is given a traversing motion with the help of a speed-regulated motor.A normal weight is placed on this test fabric. To measure the fabric-to-fabric friction, another fabric can be fastened to that metallic surface. The desired amounts of normal load can be applied.

When the bottom surface with a test fabric mounted over it moves under the friction surface, a frictional pull/push will act on the top surface (friction surface) in the direction of the movement of the lower surface, because of the friction between the surfaces. The top friction surface is connected to a load cell through a linking arm. The load cell gives a signal corresponding to the frictional force acting on the fabric.

For measuring the surface roughness of the fabric, the instrument employs a LVDT sensor. A very fine probe touches the fabric surface. When the fabric is moved, the probe is deflected onto the vertical plane. That displacement will be converted into an electrical signal by the LVDT. The movement of the probe in the vertical direction is taken as a measure of the surface roughness of the fabric.

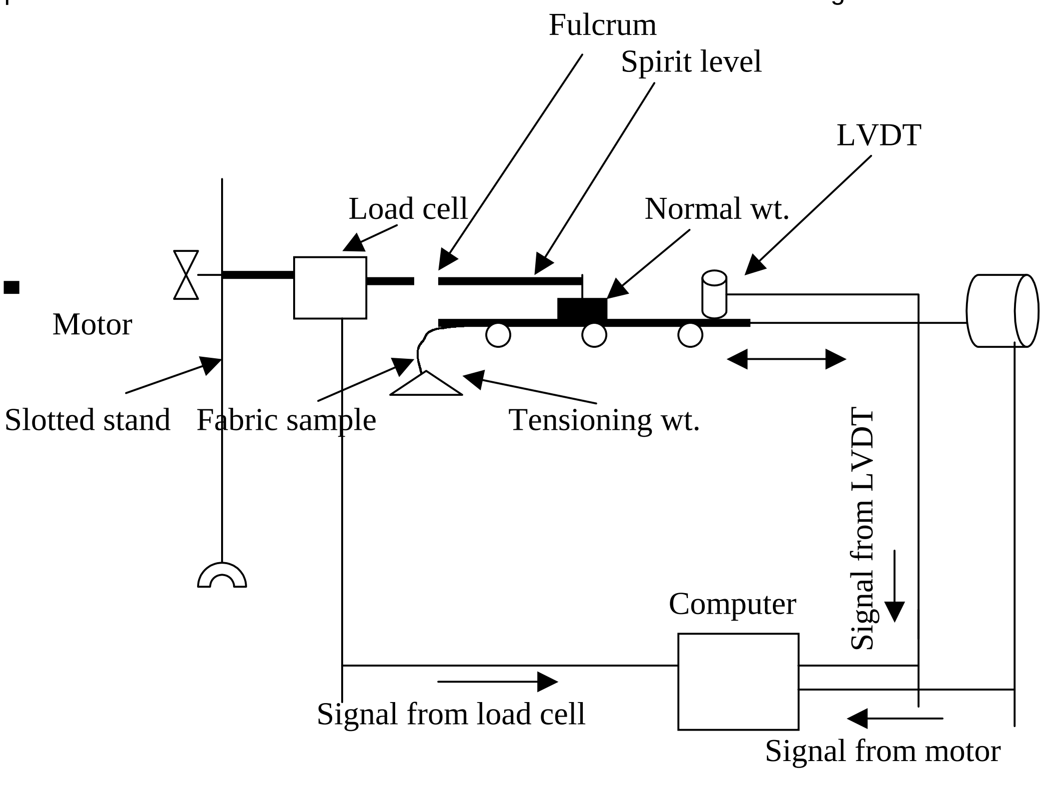

Figure 1. Schematic diagram of fabric friction and roughness tester

Both signals are interfaced with a personal computer using an analogue-to-digital converter card (ADC card). Data will be obtained in graphic form. The typical friction and surface roughness traces are shown in Figures 2 and 3 respectively.

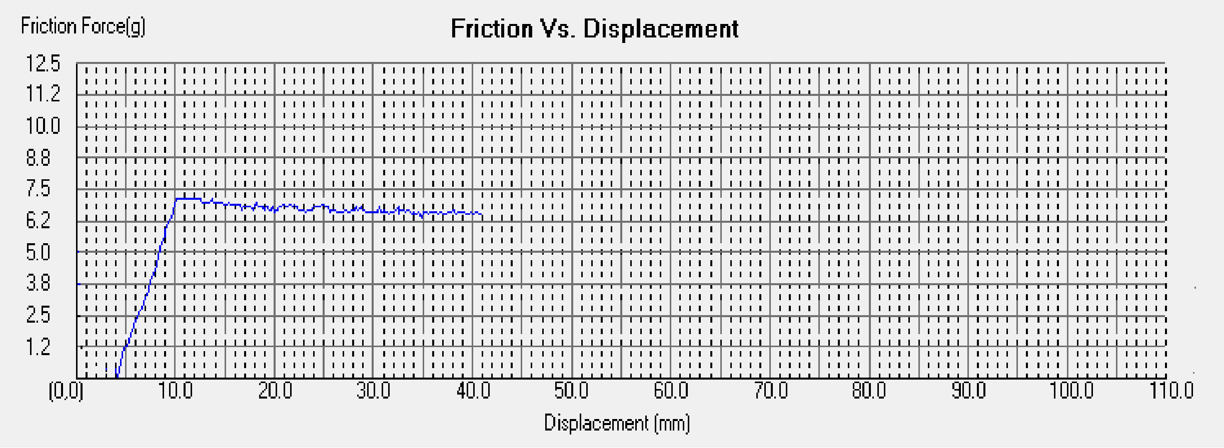

Figure 2. Typical fabric friction trace

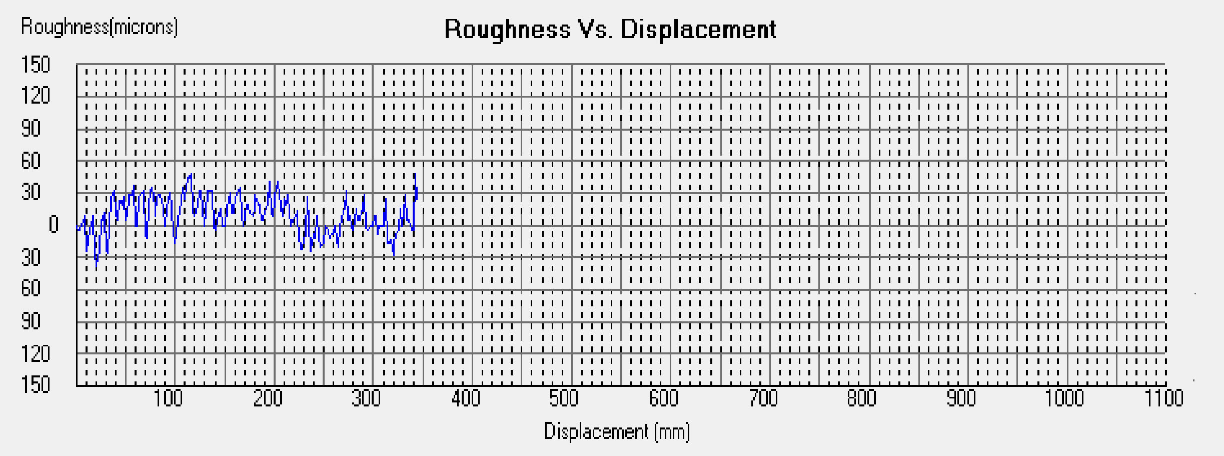

Figure 3. Typical surface roughness trace of woven fabric

Experimental Plan

Materials

Eight commercial fabrics were collected for experimental study. The fabrics are of 100% polyester, 100% viscose, polyester-cotton and polyester-viscose blend with similar structural parameters. The physical parameters of these three groups of fabrics are given in Table 1.

Measurement of fabric friction

The measurement of friction of various fabrics was carried out on the instrument which we developed. Fabric-to-fabric and fabric-to-metal friction was measured. The former simulates the interaction between clothing items. In all fabrics, fabric-to-fabric friction was studied by taking two samples of the same fabrics. Fabric-to-metal friction represents fabric movement over a hard surface. Here highly polished aluminium was used. Five readings were taken on each fabric. Two different samples of the same material were used for the frictional force measurement of a fabric. One end of the fabric was clamped, and the other end was maintained under a tension of 10 cN/cm of width with the help of a clamping weight. The area of the metallic block (friction surface) is 20 cm^2. The weight of the metallic block with the linking arm is 60 g. By maintaining the extra weight over this block, normal pressure can be increased. Here, the normal loads that were used range from 60 to 100 g at increments of 10 g. The speed of the moving plate is 50 mm per minute. The length of the traverse is

50 mm. From the graph, the static frictional force (F_s) and kinetic frictional force (F_k) were obtained. The ratio (F/N), where N is the normal load, was calculated for both the static and kinetic frictions.

Table 1. Details of fabric physical parameters

Sample no.	Fabric Type	Ends per cm	Picks per cm	Warp count, N_e	Weft count, N_e	Warp crimp, %	Weft crimp, %	Warp crimp height, mm	Weft crimp height, mm	Fabric wt., g/m^2	Thicknes, μm
1	100% Polyester (spun)	23	20	2/32	2/30	4.5	5.1	1.03	0.96	179	0.31
2	P/C 80/20	24	21	2/24	2/28	9.2	3.2	1.42	0.73	217	0.39
3	P/C 70/30	24	21	2/28	2/28	9.8	5.6	1.47	0.96	218	0.37
4	P/C 50/50	24	21	2/28	2/28	6.7	8.1	1.20	1.16	210	0.38
5	100% Viscose (spun)	24	20	2/30	2/30	5.6	9.1	1.15	1.23	186	0.32
6	P/V 40/60	24	21	2/28	2/28	8.9	6.7	1.40	1.06	198	0.36
7	P/V 50/50	24	21	2/28	2/28	7.6	6.2	1.29	1,02	196	0.33
8	P/V 70/30	24	21	2/28	2/28	6.0	5.3	1.18	0.94	194	0.33

Results and Discussion

Frictional properties of fabrics

Table 1 shows that the fabrics do not differ much in their constructional parameters, but they do differ in the blend proportion. 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 $(F/N)_k$. When no subscript is used with the (F/N) ratio, both the static and kinetic friction ratios are referred to. Static friction is the force which opposes the tendency of a body at rest to start to move over another surface, and kinetic friction is the force which opposes the motion of two surfaces moving on each other.

Fabric-to-metal friction

Table 2 shows the static and kinetic frictional behaviour of fabrics against a polished metal surface. The (F/N) values along the warp and weft directions are almost identical, as the metallic surface does not interact structurally with the fabric surface. So, in this case the friction in warp direction is reported. It is evident from Table 2 that 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 [1]. The relationship is

$$(F/A) = k\,(N/A)^{n} \text{ or, } \log (F/A) = \log k + n \log (N/A)$$

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

This relation can be explained using the adhesion theory of friction. According to this theory, with the increase in the normal pressure, there will be a reduction in the true area of contact. Here the relation between changes in the normal load to change in the real area of contact is nonlinear, causing a reduction in the (F/N) value with an increase in the normal load. This may also be explained due to the bending of the surface fibres towards the fibre bulk, and the lateral compression of the yarns at the higher pressure; in other words, the threads are flattened, the surface becomes more regular, and there is a more uniform distribution of the load resulting in the reduction of friction values.

It is clear from Table 2 that the fabric-to-metal friction in the case of 100% polyester is lower than the polyester/cotton blended fabrics. This may be due to the fact that the yarn becomes fuzzier with the addition of the cotton component. These surface fibres will offer more resistance to the motion. The spaces between the threads will also be covered by these surface fibres, so the real area of contact will increase; this also results in higher friction. In the case of 100% polyester, the population of the surface fibres is less. The yarns in the fabric are well distinguished from one another, and offer less area of real contact, and thus less resistance to motion. With the increase in the cotton content, the population of the surface fibres increases and offer more resistance to sliding. Here fabric no. 2 (P/C 80/20) has shown higher (F/N) values than that of fabric no. 3 (P/C 70/30). In addition to these factors, the differences in yarn count and variation in the thickness may cause comparatively higher friction.

Table 2. Fabric-to-metal frictional characteristics at different normal loads

Sample no.	Friction type	Normal pressure (cN/cm^2)				
		3	3.5	4	4.5	5
1	$(F/N)_s$	0.160	0.159	0.158	0.157	0.157
	$(F/N)_k$	0.150	0.149	0.149	0.148	0.146
2	$(F/N)_s$	0.223	0.221	0.220	0.219	0.218
	$(F/N)_k$	0.215	0.212	0.210	0.208	0.216
3	$(F/N)_s$	0.218	0.216	0.215	0.214	0.213
	$(F/N)_k$	0.211	0.208	0.207	0.205	0.203
4	$(F/N)_s$	0.262	0.260	0.258	0.256	0.254
	$(F/N)_k$	0.248	0.245	0.242	0.239	0.236
5	$(F/N)_s$	0.218	0.215	0.213	0.211	0.210
	$(F/N)_k$	0.207	0.215	0.214	0.211	0.209
6	$(F/N)_s$	0.205	0.199	0.197	0.196	0.195
	$(F/N)_k$	0.198	0.190	0.188	0.186	0.185
7	$(F/N)_s$	0.198	0.194	0.192	0.191	0.190
	$(F/N)_k$	0.187	0.182	0.180	0.178	0.176
8	$(F/N)_s$	0.185	0.184	0.183	0.182	0.181
	$(F/N)_k$	0.174	0.173	0.171	0.170	0.168

Table 2 shows that 100% viscose yarns lead to higher (F/N) values than 100% polyester does, and the frictional ratio reduces with the reduction of the viscose component in the viscose/polyester blended fabrics. Viscose is a soft material; it may thus have a higher contact area and so result in higher friction. Also, with the increase in the polyester component, the surface of fabric might become smoother, resulting in lower friction.

The relationships between normal load and fabric to the metal frictional force for polyester & polyester/cotton blended fabrics and viscose & viscose/polyester blended fabrics are shown in Figures 4 and 5 respectively.

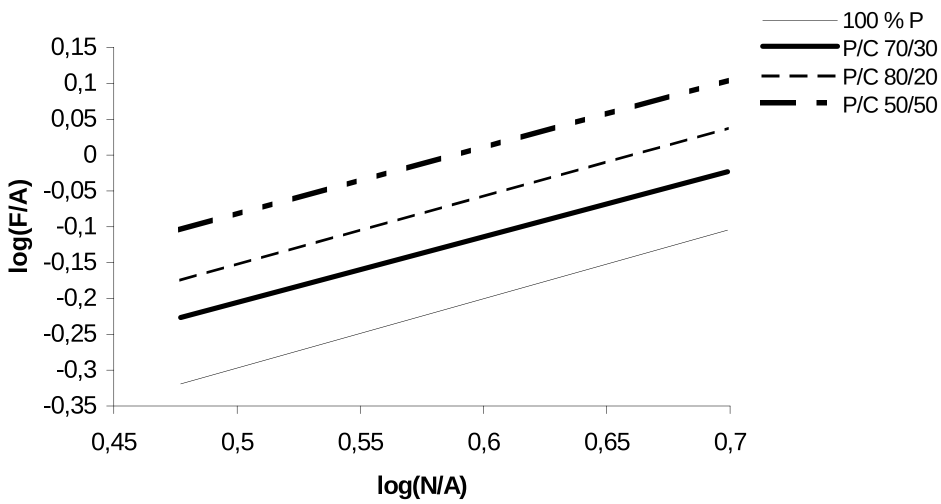

Figure 4. Relationship between (F/A) and (N/A) for polyester and P/C blended fabrics (fabric-to-metal friction)

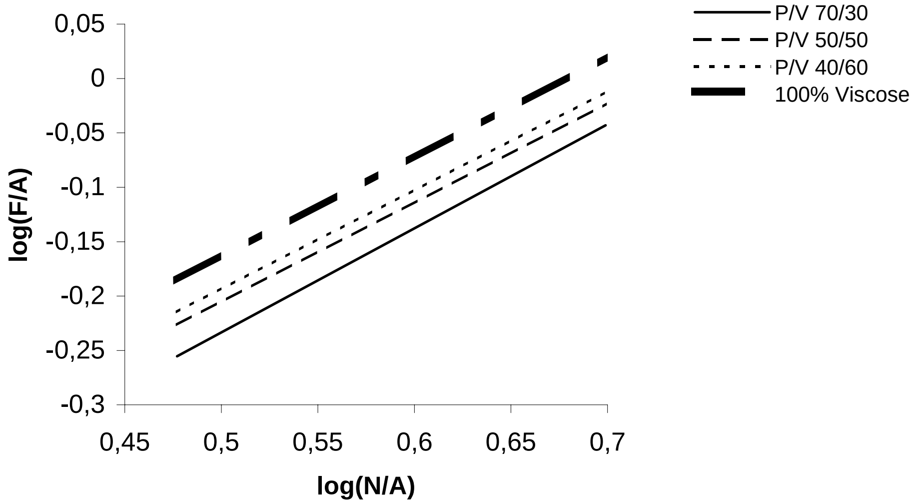

Figure 5. Relationship between (F/A) and (N/A) or viscose and P/V blended fabrics (fabric-to-metal friction)

The values of k, n and the coefficient of determination R^2 obtained using regression analysis are given in Table 3. The values of n are close to 1 for all the fabrics, indicating that the relationship between frictional force and normal load is close to linear. The ratio k/n indicates the frictional characteristics of the fabrics. The higher the ratio, the higher the frictional force will be. This ratio can be used to compare different fabrics.

Table 3. Frictional parameters of fabrics (Fabric-to-metal friction)

Sample no.	n	k	k/n	R^2
1	0.966	0.166	0.172	0.99
2	0.956	0.229	0.239	0.98
3	0.954	0.234	0.246	0.98
4	0.940	0.28	0.298	0.98
5	0.928	0.235	0.253	0.99
6	0.956	0.194	0.203	0.98
7	0.916	0.217	0.236	0.98
8	0.911	0.224	0.245	0.98

Fabric-to-fabric friction

The warp-wise fabric-to-fabric friction at various normal pressures is tabulated in Table 4. Compared to the fabric-to-metal friction, the fabric-to-fabric friction is very high. When two fabrics are in contact they may interact structurally, which contributes to high friction. Sample no. 1 (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. When the fabric is in contact with another fabric, the surface fibres penetrate into the domain of the other fibres of the contacting fabric, and form a loose inter-fabric structure. The (F/N) ration represents the energy lost in breaking this loose structure, while resistance comes from the adhesion at contact points of fibres and the bending of fibres in the moving fabric surface. 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. When compared with the other P/C blends, the crimp heights are also correspondingly lower, resulting in lesser resistance due to interlocking of the structure during sliding. The difference between the (F/N) values of fabric no. 2 and fabric no. 3 is small. This might be due to the presence of coarser yarns (as warp) in fabric no. 2, which offers more area of real contact and thus higher frictional resistance. The 100% viscose has shown slightly higher friction than that of 100% polyester. With the increase in the viscose content, the increase in the (F/N) values is considerably less. The P/V blends show lower (F/N) values than in P/C blends. The difference in the type of fibre, the surface fibre population, and their length distribution and low load-compressible properties of the respective fabrics may cause these differences in the frictional properties of the P/C and P/V blend fabrics.

Table 4. Fabric-to-fabric frictional characteristics at different normal load (warp direction)

Sample no.	Friction type	Normal pressure (cN/cm^2)				
		3	3.5	4	4.5	5
1	$(F/N)_s$	0.742	0.721	0.706	0.688	0.664
	$(F/N)_k$	0.653	0.640	0.629	0.618	0.596
2	$(F/N)_s$	0.992	0.965	0.937	0.914	0.889
	$(F/N)_k$	0.850	0.836	0.817	0.800	0.783
3	$(F/N)_s$	1.036	0.976	0.950	0.932	0.912
	$(F/N)_k$	0.873	0.834	0.813	0.801	0.770
4	$(F/N)_s$	1.138	1.071	1.042	0.989	0.978
	$(F/N)_k$	0.952	0.886	0.871	0.852	0.837
5	$(F/N)_s$	0.804	0.784	0.761	0.747	0.733
	$(F/N)_k$	0.652	0.648	0.625	0.615	0.603
6	$(F/N)_s$	0.825	0.806	0.779	0.760	0.743
	$(F/N)_k$	0.737	00.723	0.705	0.688	0.675
7	$(F/N)_s$	0.918	0.903	0.880	0.861	0.842
	$(F/N)_k$	0.770	0.751	0.740	0.729	0.714
8	$(F/N)_s$	0.915	0.905	0.880	0.860	0.835
	$(F/N)_k$	0.787	0.770	0.761	0.744	0.729

The (F/N) values along the weft direction were found to be slightly more than that of warp direction. This may be due to the higher crimp/crimp height and higher thread density along the warp direction. When the fabric moves in the weft direction, these crown points along the warp will interlock and offer more resistance to sliding.

The relation between frictional force and normal load is observed to be logarithmic, and the values of k and n are calculated using regression analysis, and the values are given in Table 5. The value of n decreases and k increases with the increase in the cotton content. The increase in the value of k indicates that the number of contacts at the interface of the fabrics rises with the increase in the cotton content]]. The decrease in the value of n indicates the elastic deformation of the interface with the increase in cotton content. The value of k/n increases with the increase in the cotton content.

Table 5. Frictional parameters of fabrics (during fabric-to-fabric friction)

Fab. No	Warp				Weft			
	n	k	k/n	R^2	n	k	k/n	R^2
1	0.795	0.933	1.173	0.989	0.799	0.933	1.168	0.987
2	0.787	1.256	1.596	0.975	0.744	1.347	1.81	0.978
3	0.756	1.34	1.772	0.968	0.695	1.463	2.105	0.921
4	0.697	1.579	2.265	0.935	0.682	1.627	2.386	0.946
5	0.818	0.982	1.2	0.981	0.833	0.952	0.142	0.983
6	0.79	1.042	1.319	0.99	0.782	1.076	1.378	0.974
7	0.828	1.114	1.345	0.986	0.808	1.176	1.46	0.963
8	0.818	1.127	1.377	0.976	0.815	1.139	1.398	0.932

The lower values of k for P/V blended fabrics as compared to that of P/C blended fabrics indicates the lesser population of surface fibres at the interface in the case of P/V blends. The ratio of k/n follows the same trend as the (F/N) values of the corresponding fabrics.

Conclusions

The following observations can be made, based on the present study of the series of commercially available fabrics:

For all the fabrics at different levels of normal load, the kinetic friction is always lower than the static friction.

The normal load and the frictional force follow a logarithmic relationship for all the fabrics. The values of n and k are specific to each individual fabric.

Fabric-to-metal friction is less sensitive to fabric morphology and rubbing direction, whereas the fabric-to-fabric friction is highly sensitive to these factors.

Fabric friction is affected by many factors such as the type of fibre, type of blend, blend proportion, yarn structure, fabric structure, crimp and crimp height, compressibility etc.
P/C and P/V blended fabrics show higher fabric-to-fabric friction than 100% polyester or 100% viscose.

P/C blended fabrics show higher frictional force than that of P/V blended fabrics for the same geometrical parameters of the fabrics.

In P/C blended fabrics, as the cotton component increases, the frictional force increases; and in P/V blended fabrics, as the viscose component increases, the frictional force also increases.

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