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FRICTORQ, ACCESSING FABRIC FRICTION WITH A NOVEL FABRIC SURFACE TESTER

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Abstract

A new method to characterise the coefficient of friction of textile fabrics is proposed. The principle is based on the dry clutch, where an annular shaped flat upper body that is kept still, rubs against a lower flat surface, which rotates around a vertical axis at a constant angular velocity. Friction coefficient between the two contacting surfaces is then proportional to the level of the dragging torque between them, measured by means of a precision reaction torque sensor. Contact pressure is constant, given by the own weight of the upper body. The signal from the torque sensor is digitalised through an electronic interface and fed into a PC where friction coefficient is worked out. Finally, experimental work is reported.

Key words:

friction coefficient, torque, fabric hand

Introduction

Many textile materials are used near humans and frequently touched by the human skin and by the human hand in particular, namely clothing, home furnishings and automotive fabrics. For this reason, the interaction with the human senses is an essential performance property [1]. Traditionally, the quality and surface characteristics of apparel fabrics is evaluated by touching and feeling by hand, leading to a subjective assessment. Therefore, one of the most important characteristics of fabrics, either for clothing or technical applications is the coefficient of friction [2]. This is an important factor regarding the objective measurement of the so-called parameter *fabric hand*. Many contributions have been given in the past to this problem and some resulted in laboratory equipment [3, 4]. A novel prototype laboratory equipment is proposed for a new method of accessing the friction coefficient of fabrics that is easy to use, very precise and should be available at an acceptable cost.

The model

Friction Coefficient is not an inherent characteristic of a material or surface, but results from the contact between two surfaces [5]. The new method consists of characterising the coefficient of friction between two flat surfaces, namely textile fabrics, based on torque evaluation. Initially, to simplify the measuring conditions, *fabric-to-fabric* was mostly used, the same fabric or a standard fabric against the test fabric. Later, a standard contact surface has also been investigated.

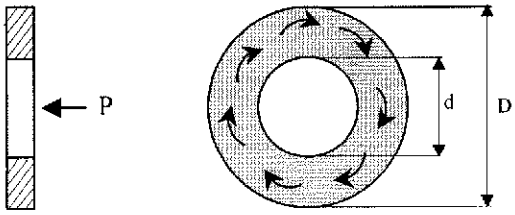

Figure 1. Geometry of the model

The principle is based on a ring shaped body rubbing against a flat surface as shown in the model of Figure 1. There are two bodies: the upper one with a contact surface of an annular geometry, which is placed over a horizontal flat lower sample. The second one is forced to rotate around a vertical axis at a constant angular velocity. Friction coefficient is then proportional to the level of torque being measured by means of a high precision torque sensor. Contact pressure between both samples is kept constant and is given by the ratio between the own weigh of the upper element and contact area. In this model, torque, T, is given by equation 1, [6], where μ is the coefficient of friction, **D** and **d** are the outer and inner diameters, **r** is the variable radius and **p** is pressure on an elemental area.

$$T = 2.\pi.\mu.\int_{d/2}^{D/2} p.r^2.dr \qquad (1)$$

One of the possible assumptions is uniform pressure, that is, the normal contact force **P** is uniformly distributed over the entire area. Integrating and replacing **p** by its value, given by equation 2,

$$p = \frac{P}{A} = \frac{4.P}{\pi.(D^2 - d^2)} \qquad (2)$$

equation 3 gives the coefficient of friction, μ, as a function of the torque **T** being measured, the vertical load **P**, and the geometry of the contact area in terms of the outer and inner diameters, **D** and **d**, respectively.

$$\mu = \frac{3.T}{P}\frac{(D^2 - d^2)}{(D^3 - d^3)} \qquad (3)$$

The design

Exploratory work led to the establishment of a number of design parameters, namely contact pressure, **p**, initially set to 2,9 kPa and linear velocity in the middle radius of the annular upper body. The geometry of the model could then be defined. With a final speed of approximately 0,75 r.p.m. at the shaft of the lower body, linear sliding velocity at the middle radius of the upper body area was 1,77 mm/s. The design of FRICTORQ includes a stationary reaction torque sensor bolted to the instrument top frame plate. This plate is pivoted so that it can be hand rotated by the operator away from the test area, to make room for the clamping of fabric samples. The lower sample support is the rotating element. This is basically an aluminium disk with a vertical shaft supported on rolling bearings for reduced friction and precise movement. The final transmission from the DC geared motor is carried out by a miniature timing belt drive.

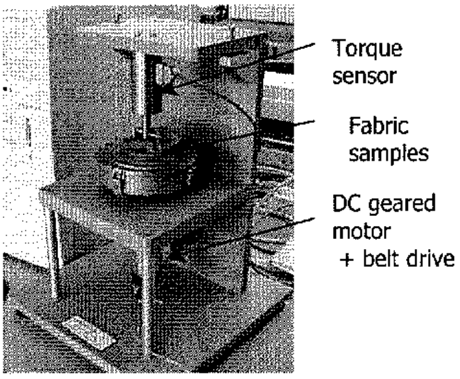

Figure 2. FRICTORQ Laboratory prototype

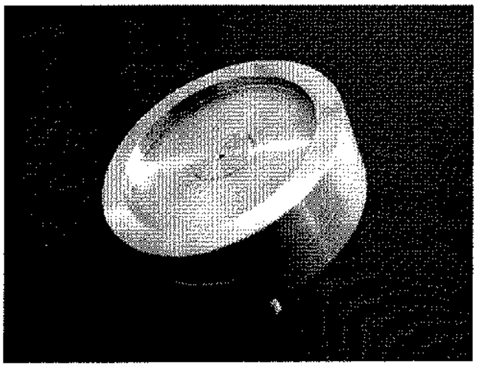

Figure 3. Standard Metallic body

Figure 2 is a general view of FRICTORQ. The horizontal bar at the end of the torque sensor shaft is responsible for holding stationary the upper body while the lower one rotates. This causes the rising of a dragging torque from the friction between the two bodies, being supported and measured by the stationary reaction torque sensor.

The working principle

After setting up the fabric samples, the upper one centered over the lower one by means of a centering needle, the torque sensor mounting plate is rotated to its working position. An appropriate identification code is introduced, as well as the weight of the upper fabric sample in grams that is added to **P** and the desired test duration in seconds. When the experiment set time runs out (20 seconds was initially used), the process is automatically stopped. Data from the torque sensor is saved and in real time represented in graphic mode. Figure 4 represents two graphic displays of experiments showing the most relevant parameters. In Figure 4a, that corresponds to a fabric-to-fabric situation, initially, while torque is building up, the sample stays static and the output is substantially a straight line. When relative motion starts, torque falls instantly. The pick value gives the static friction coefficient, μ_{sta}. The reaction torque then tends to stabilise, showing a moderate pending up to the end of the experiment. To compute the dynamic friction coefficient, data from the first 10 seconds of the process is ignored to allow the signal to stabilise. The system then computes the average torque in the interval from 10 to 20 seconds and, using equation 3, gives the kinetic or dynamic friction coefficient, μ_{kin}. The values of the maximum and average torque are also displayed in small boxes. In Figure 4b, which corresponds to a steel-to-fabric situation, the shape is quite different: The pick value is not evident and the shape of the graph is much more stable and nearly horizontal for the duration of the test. For that reason, static friction is ignored and for dynamic friction data collected between 5 and 15 seconds of the test is used.

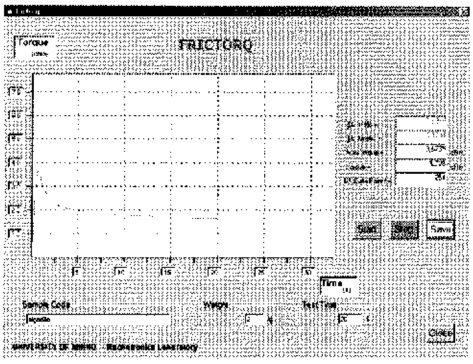

Figure 4a. Graphic output for Fabric-to-fabric

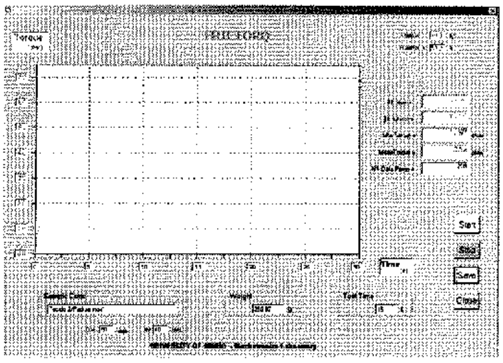

Figure 4b. Graphic output for Steel-to-fabric

Experimental

Fabric-to-Fabric

Tests with different fabrics at different processing conditions were carried out, and typical obtained results are shown in Figure 5.

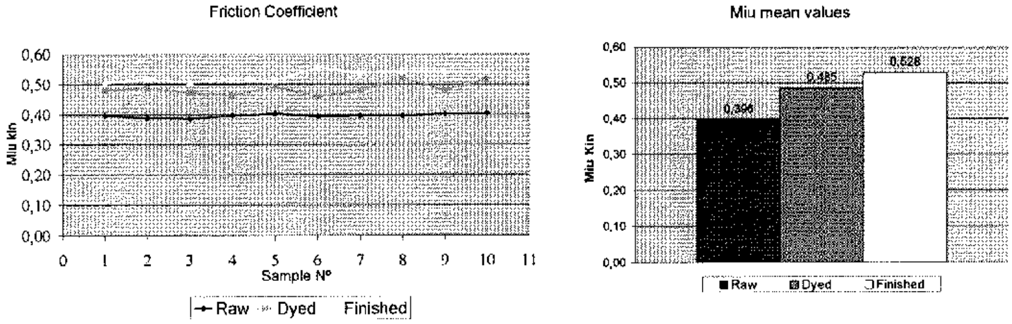

Figure 5. Comparison of μ_{Kin} for a plain weave cotton fabric in different processing stages

Initially the tests were made by dragging two samples of the same test fabric, one mounted in the upper body and the other in the lower one. Under these conditions, Figure 5 represents kinetic friction coefficient results for 10 samples of a cotton fabric, plain weave, 260,1 g/m^2, in three different stages, raw, dyed and finished. For this experiment, the mean values were worked, which quite clearly show a coefficient of friction characteristic for each of the three different fabric conditions.

This method of testing fabric against itself originated however a difficulty when trying to compare results between different fabrics. In fact this method works as if the standard would be always changed. A decision was taken to explore a standard or reference contact surface.

Standard surface-to-fabric

In order to avoid the encountered difficulties the next step was to replace the upper sample with a standard surface. First tests were carried out using SM 25 fabric (used in Martindale tests) as the upper sample, and second, a standard metallic body was investigated. Table 1 is a description of the materials and contacting surfaces used in these sets of tests. It reads as follows: Ref.1 corresponds to an experiment were a 95g/m^2 Not finished plain weave cotton fabric lower sample was tested against a SM 25 standard fabric as the upper sample.

Table 1. Identification of tests conditions

Conditions	**Plain weave**	**Plain weave**	**Twill weave**	**Twill weave**
Material	Cotton	Cotton	Cotton	Cotton
Fabric weight (g/m^2)	95	95	180	180
Processing stage	Not finished	Finished	Not finished	Finished
SM25 std fabric	**1**	**2**	**3**	**4**
Std metallic body	**5**	**6**	**7**	**8**

SM 25 standard fabric-to-fabric

Using SM 25 Standard fabric as the upper sample, tests in conditions 1 to 4 were carried out and the results are represented in the graphs of figures 6 and 7. Table 2 lists the corresponding statistical descriptives.

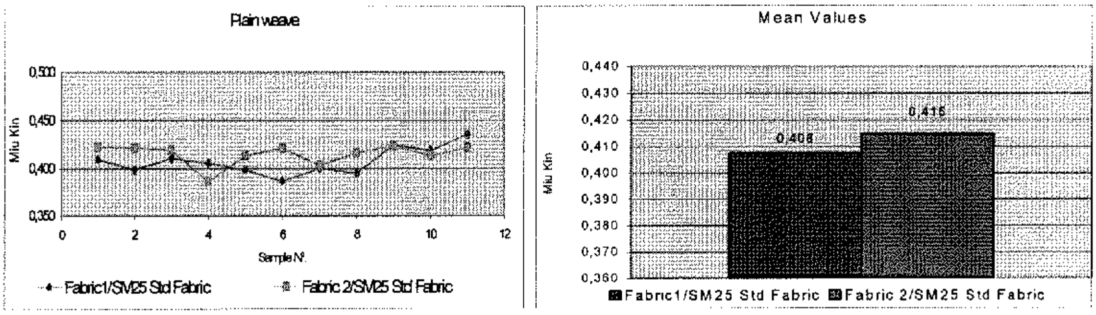

Figure 6. Comparison of μ Kin for the same plain weave cotton fabric, not finished (1), finished (2)

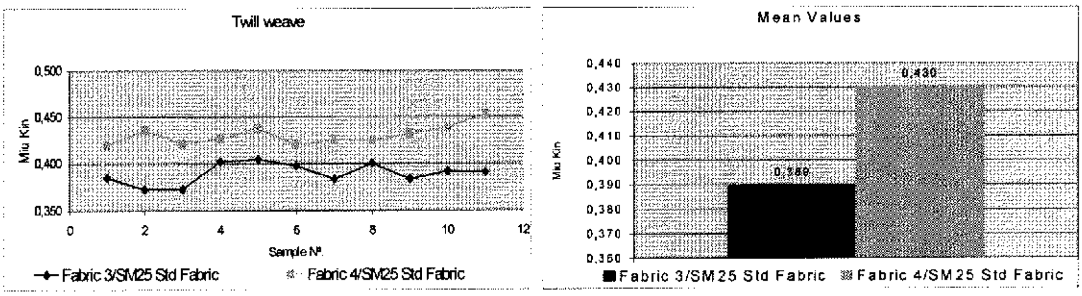

Figure 7. Comparison of μ Kin for the same twill weave cotton fabric, not finished (3), finished (4)

Table 2. Statistical descriptives from the results with SM25 Std Fabric

Test ref.	N	Mean µ Kin_StdF	Std. deviation	Std. error	95% confidence interval for mean		Min.	Max.
					Lower bound.	Upper bound.		
1	11	0.40764	0.01419	0.00428	0.39810	0.41717	0.387	0.435
2	11	0.41491	0.01135	0.00342	0.40728	0.42254	0.386	0.424
3	11	0.38955	0.01112	0.00335	0.38207	0.39702	0.373	0.405
4	11	0.43036	0.01022	0.00308	0.42350	0.43723	0.42	0.453
Total	44	0.41061	0.01871	0.00282	0.40492	0.41630	0.373	0.453

To study the obtained results, SPSS 12.0® statistical package, to make a multiple comparison analysis, and Scheffe test (mean for groups in homogeneous subsets) were used. The obtained results are listed in Tables 3 and 4.

Table 3. Multiple comparisons of the results with SM25 Std fabric

(I) Test ref.	(J) Test ref.	Mean difference (I-J)		Std. error	Sig.	95% confidence interval	
						Lower bound.	Upper bound.
1	2	-0.00727		0.00504	0.56083	-0.02198	0.00743
	3	0.01809	*	0.00504	0.01016	0.00339	0.03279
	4	-0.02273	*	0.00504	0.00084	-0.03743	-0.00802
2	1	0.00727		0.00504	0.56083	-0.00743	0.02198
	3	0.02536	*	0.00504	0.00018	0.01066	0.04007
	4	-0.01545	*	0.00504	0.03587	-0.03016	-0.00075
3	1	-0.01809	*	0.00504	0.01016	-0.03279	-0.00339
	2	-0.02536	*	0.00504	0.00018	-0.04007	-0.01066
	4	-0.04082	*	0.00504	0.00000	-0.05552	-0.02611
4	1	0.02273	*	0.00504	0.00084	0.00802	0.03743
	2	0.01545	*	0.00504	0.03587	0.00075	0.03016
	3	0.04082	*	0.00504	0.00000	0.02611	0.05552

* The mean difference is significant at the 0.05 level.

Table 4. Results from Scheffe statistical analysis for SM25 Std fabric

Test ref.	N	Subset for alpha = 0.05		
		1	2	3
3	11	0.3895		
1	11		0.4076	
2	11		0.4149	
4	11			0.4303
Sig.		1	0.5608	1

Standard body-to-fabric

A new objective was then set up: To define a standard contact body that could be easily specified and made, whose surface characteristics could be easily reproduced. After a long process and a large amount of ideas, some of which were tested, a quite simple solution was proposed and evaluated: a ring shaped stainless steel probe, having a flat annular face, turned and finished by polishing on 1200 grade wet sandpaper. The contact pressure was worked out to 3,5 kPa. After this process the metal surface was measured for roughness and a consistent value of 0,1 µm for Ra was obtained. Figure 3 shows the standard metallic body on its brass support.

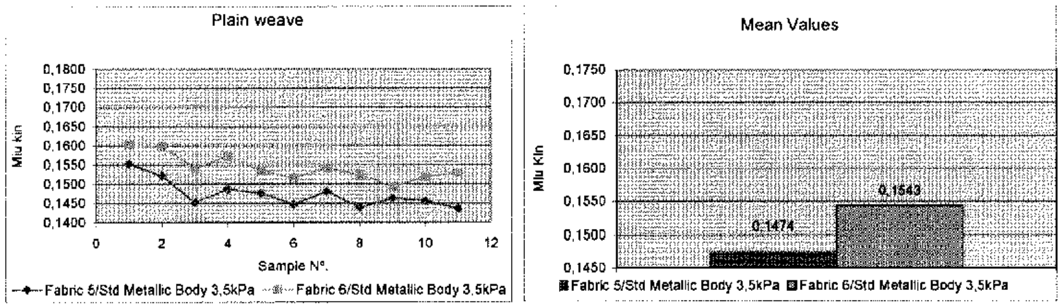

Figure 8. Comparison of μ Kin for the same plain weave cotton fabric, not finished (1), finished (2)

Using this body as the upper sample, tests in conditions 5 to 8 were carried out and the results are represented in graphs of figures 8 and 9. Table 5 lists the corresponding statistical descriptives.

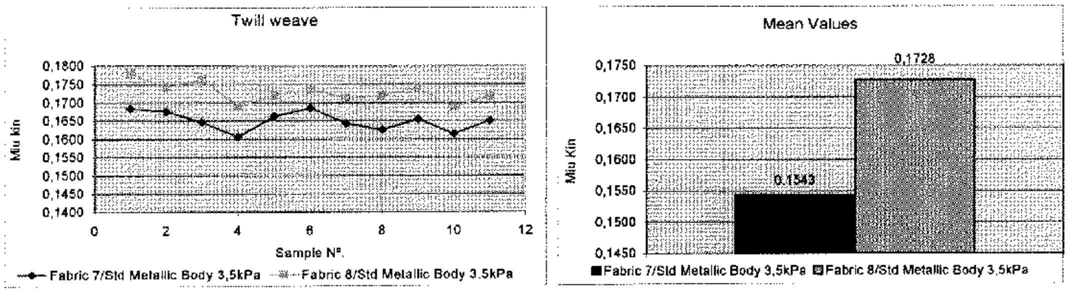

Figure 9. Comparison of μ Kin for the same twill weave cotton fabric, not finished (3), finished (4)

Table 5. Statistical descriptives from the results with std metallic body

Test ref.	N	Mean	Std. deviation	Std. error	95% confidence interval for mean		Min.	Max.
					Lower bound	Upper bound		
5	11	0.14739	0.00362	0.00109	0.14496	0.14982	0.1436	0.1553
6	11	0.15431	0.00344	0.00104	0.15200	0.15662	0.1493	0.1603
7	11	0.16495	0.00267	0.00081	0.16315	0.16674	0.1606	0.1685
8	11	0.17280	0.00278	0.00084	0.17093	0.17467	0.1687	0.1778
Total	44	0.15986	0.01031	0.00155	0.15673	0.16300	0.1436	0.1778

As well as previously, in order to study the ability of the standard metallic body to differentiate fabrics, a similar statistical analysis was done. The results obtained are listed in Tables 6 and 7.

Table 6. Multiple comparisons of the results with std metallic body

(I) Test ref.	(J) Test ref.	Mean difference (I-J)		Std. error	Sig.	95% confidence interval	
						Lower bound	Upper bound
5	6	-0.00692	*	0.00134	0.00013	-0.01084	-0.00299
	7	-0.01755	*	0.00134	0.00000	-0.02148	-0.01363
	8	-0.02541	*	0.00134	0.00000	-0.02933	-0.02148
6	5	0.00692	*	0.00134	0.00013	0.00299	0.01084
	7	-0.01064	*	0.00134	0.00000	-0.01456	-0.00671
	8	-0.01849	*	0.00134	0.00000	-0.02242	-0.01457
7	5	0.01755	*	0.00134	0.00000	0.01363	0.02148
	6	0.01064	*	0.00134	0.00000	0.00671	0.01456
	8	-0.00785	*	0.00134	0.00002	-0.01178	-0.00393
8	5	0.02541	*	0.00134	0.00000	0.02148	0.02933
	6	0.01849	*	0.00134	0.00000	0.01457	0.02242
	7	0.00785	*	0.00134	0.00002	0.00393	0.01178

* The mean difference is significant at the 0.05 level.

Table 7. Results from Scheffe statistical analysis for std metallic body study

Test ref.	N	Subset for alpha = 0,05			
		1	2	3	4
5	11	0.1473			
6	11		0.1543		
7	11			0.1649	
8	11				0.1728
Sig.		1	1	1	1

Discussion

From these experiments, for tests in conditions identified by 1, 2, 3 and 4, with the objective of studding the ability of the SM 25 Std Fabric to differentiate fabrics, 3 groups were identified - (1, 2), 3 and 4 -, which means that samples 1 and 2 could not be statistically differentiated. This situation was predictable by the observation of the sequence of the results during the tests as shown in Figure 6. Although these samples correspond in fact to the same fabric in two different processing stages, not finished (1) and finished (2), to the human touch they also looked quite similar, being very difficult to differentiate. On the other hand, samples 3 and 4, also corresponding to the same fabric in different processing stages, could be statistically differentiated and this was also predictable by the observation of Figure 7.

For tests in conditions identified by 5, 6, 7 and 8, with the objective of studding the ability of the std metallic body to differentiate fabrics, 4 groups were identified, which means that all samples are statistically different. This situation was also predictable by the observation of the sequence of the results during the tests in figures 8 and 9.

Conclusions

The experiments carried out so far have shown promising capabilities for the FRICTORQ principle and design. From the results of the experiments described above, the following conclusions can be drawn:

FRICTORQ shows capabilities of accessing friction in fabrics. Depending upon the objective, different types of tests can be made:

Fabric-to-fabric, that could be used to study situations such as fabric friction during the sewing process, where fabrics sliding needs to be prevented.

Standard surface-to-fabric. This situation was analysed in two different ways: SM 25 standard fabric-to-fabric and standard metallic body-to-fabric.

The major findings are as follows:

1. SM 25 standard fabric gave higher values for Miu (typically between 0,3730 and 0,4530), while our developed standard metallic body gave typical values between 0,1493 and 0,1778. This situation was expected, as the SM 25 surface roughness is clearly higher than the stainless steel metallic surface.
2. standard metallic body gave more accurate results, even when the fabrics were very similar to the human touch. In fact, unlikely the SM 25 Fabric, it could statistically differentiate all types of fabrics.

A more comprehensive experimental work is needed, in order to establish a full set of procedures and standards. Future work will focus on the standard metallic body optimisation, namely studding contact pressure, roughness and relative velocity. Nevertheless, this work is already a new contribution to the objective characterization of fabric surface properties.

Patent protection of this new measuring method is now pending [7].

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