Original Paper

FRICTORQ, a Novel Fabric Surface Tester:
a Progress Report

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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.

Keywords: frictorq, friction coefficient, torque, fabric hand

1. 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, especially for clothing, 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 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.

2. The Model

Coefficient of friction is not an inherent characteristic of a material or surface, but results from the contact an interaction between two surfaces [5]. This entirely new method consists of characterising the coefficient of friction between two flat surfaces, namely a textile fabric and a standard surface, based on a relative rotary movement between them by 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.

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 fabric 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 during the test and is given by the ratio between the own weight of the upper element and the contact area.

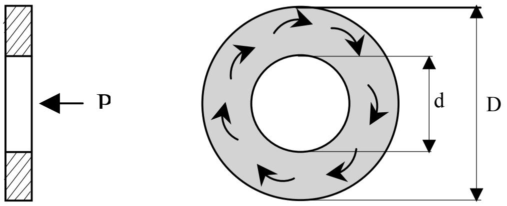

Fig.1 Geometry of the model

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.

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

Uniform pressure is assumed, 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, 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.

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

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

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 approximately 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 the fabric samples. The lower sample support is the rotating element. This is basically a disk with a vertical shaft supported on rolling bearings for reduced friction and precise movement. A pressure ring clamps the sample on a matching conical surface. The final transmission from the DC geared motor is carried out by a miniature timing belt drive.

Figure 2 is a general view of FRICTORQ in a fabric-to-fabric configuration [7]. The horizontal bar at the end of the torque sensor shaft is responsible for holding stationary the upper contact 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.

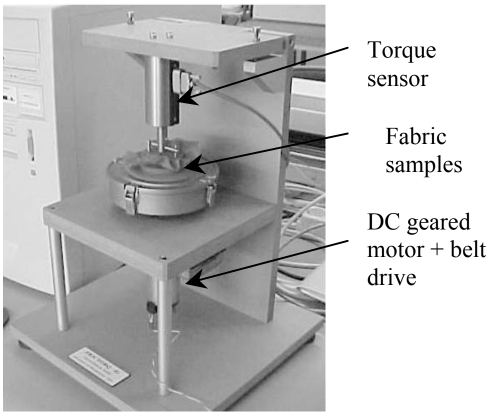
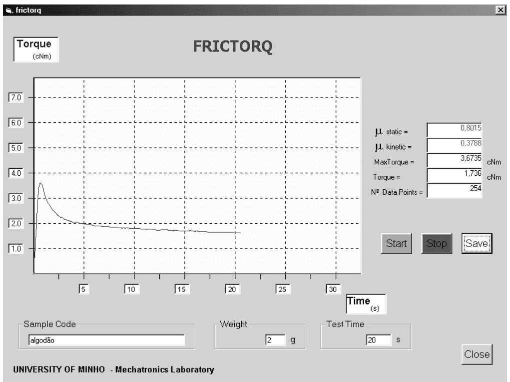


Fig.2 FRICTORQ prototype

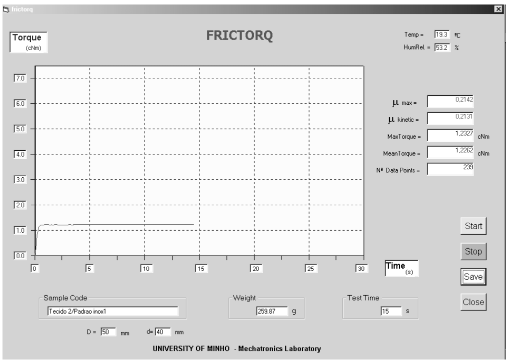
4. The Working Principle

After setting up and clamping the fabric sample in place, the upper contact body is centred over it by means of a centring needle. The torque sensor mounting plate is then swung back to its working position. An appropriate identification code is introduced, as well as the weight of the upper body **P** in grams, the diameters **D** an **d** in millimetres and the desired test duration in seconds. When the experiment set time runs out (20 seconds was mostly used), the process is automatically stopped. Data from the torque sensor is saved and in real time represented in graphic mode. Figures 3a and 3b represent two graphic displays of experiments showing the most relevant parameters. In figure 3a, 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, $\mu_{sta.}$ The reaction torque then tends to stabilize, showing a moderate pendent up to the end of the experiment.



μ static = 0,8015
μ kinetic = 0,3788
MaxTorque = 3,6735 cNm
Torque = 1,736 cNm
Nº Data Points = 254
Sample Code: algodão
Weight: 2 g
Test Time: 20 s

Fig.3a Graphic output for fabric-to-fabric



Temp = 19.3 ºC
HumRel. = 53.2 %
μ max = 0,2142
μ kinetic = 0,2131
MaxTorque = 1,2327 cNm
MeanTorque = 1,2262 cNm
Nº Data Points = 239
Sample Code: Tecido 2/Padrao inox1
Weight: 259.87 g
Test Time: 15 s
D = 50 mm
d= 40 mm

Fig.3b Graphic output for steel-to-fabric

To compute the dynamic friction coefficient, data from the first 5 seconds of the process is ignored to allow the signal to stabilize. The system then computes the average torque in the interval from 5 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 3b, 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 was also used.

5. Experimental

Initially, to simplify the measuring conditions, *fabric-to-fabric* was mostly used. However, the method of testing fabric against itself originated a difficulty when trying to compare results between different fabrics. In fact it works as if the standard surface was always changed. This situation dictated the need to search for a standard fabric to be used against the test fabric.

On a later stage, 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. For this, 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. The metal surface was measured for roughness and a consistent value of 0,1 µm for Ra was obtained. Figure 4a shows this standard smooth metallic body (SMB) on its brass support.

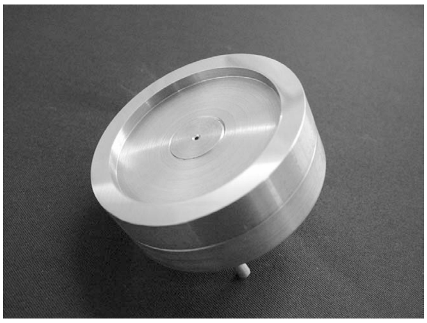


Fig.4a Smooth metallic body (SMB)

On the following stage, a uniform thin texture was applied to the metal surface for increasing its roughness. This textured metallic body (TMB) is shown in figure 4b.

Fig.4b Textured metallic body (TMB)

Tests were then carried out using SM 25 fabric (used in Martindale tests) and the Smooth Metallic body (SMB) described above as the standard surface. From the results of the experimental work some conclusions could be drawn [8]:

1. SM 25 Standard Fabric gave higher values for Miu (typically between 0,3730 and 0,4530), while our proposed Smooth 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. Smooth 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 tested fabrics.

In order to access the influence of contact pressure a new set of tests was carried out with different fabrics and in different conditions (Refs. 82-84 and 92-94 of table 1). Another study was done to access FRICTORQ capabilities for measuring friction in fabrics in comparison with a respected commercially available equipment, KES. For this comparative analysis, friction tests were made in samples of the same fabric using KES (ref. 100), FRICTORQ SMB (ref. 101) and FRICTORQ TMB (ref.102). A description of the materials and test conditions used in these sets of tests are given in tables 1 and 2 of the Appendix.

5.1 Influence of the contact pressure

For this study, in order to be able to increase the contact pressure, a new Smooth Metallic Body, SMB, with smaller diameters **D** and **d** of 28 and 24 millimetres respectively was made (Ø 28/24), giving contact pressures of 3.5, 10 and 20 kPa depending upon the weight of the supporting element. Fabrics with refs. 80 and 90 were used in this experiment. Friction tests were carried out with FRICTORQ and the results are represented in the graphs of figures 5 and 6. Tables 3 and 4 of the Appendix list the corresponding statistical descriptives.

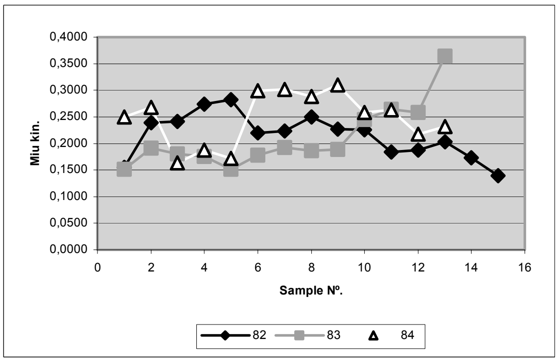


Fig.5a Individual test results with fabric 80

The obtained results were analysed using SPSS 12.0® statistical package. In the Appendix, tables 5 and 7 show the multiple comparison analysis and tables 6 and 8 the mean for groups in homogeneous subsets (Scheffe test).

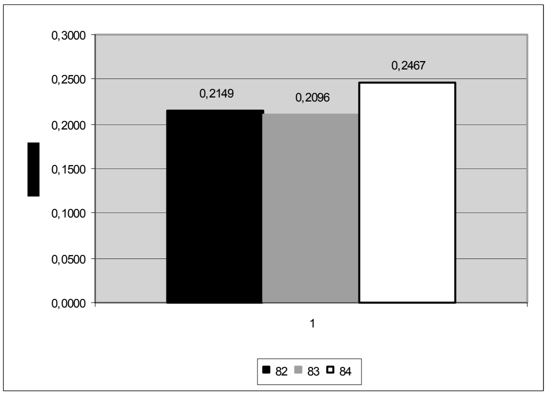


Fig.5b Mean values with fabric 80

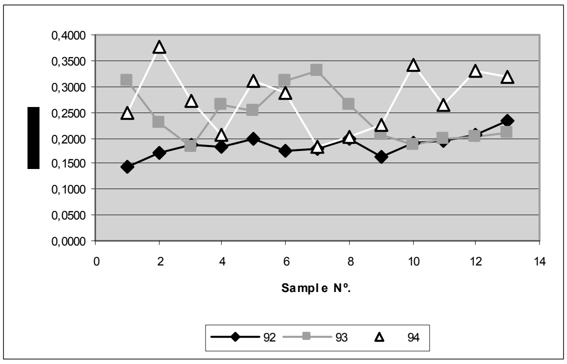


Fig.6a Individual test results with fabric 90

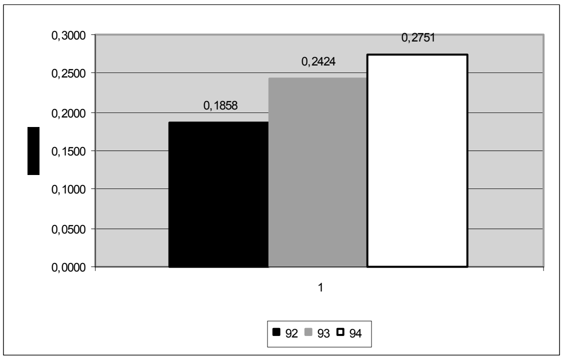


Fig.6b Mean values with fabric 90

5.2 Comparison between KES and FRICTORQ

Using fabric with ref. 100, tests with KES-F and FRICTORQ with SMB, (Ø 50/40), and TMB, (Ø 50/40), with a contact pressure of 3,5 kPa, were carried out. The results are represented in the graphs of figures 7a and 7b and table 9 of the Appendix lists the corresponding statistical descriptives.

Again, 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 10 and 11 of the Appendix.

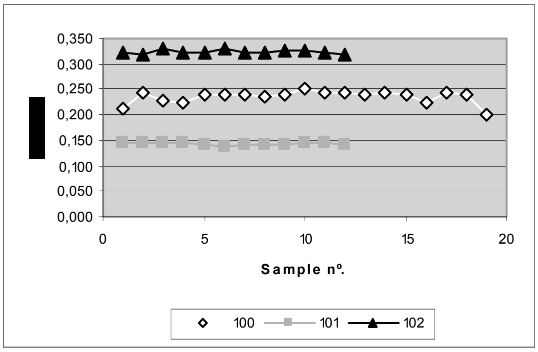


Fig.7a Individual test results with fabric 100

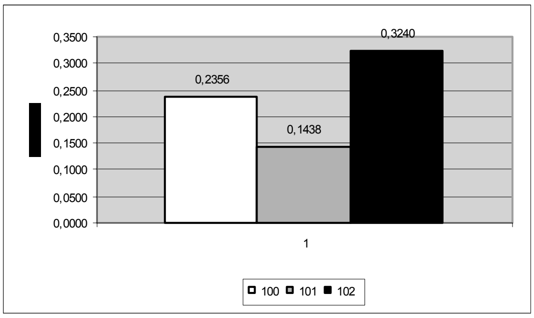


Fig.7b Mean values with fabric 100

6. Discussion

The results of the experimental work gave the following indications:

Influence of contact pressure: Experiments with the smooth surface were made using contact pressures of 3.5, 10 and 20 kPa, in both thin (Ref. 80) and thick fabrics (Ref. 90). The results have shown a slight difference when using SMB at 20 kPa with thick fabrics, with no statistical difference when using 10 and 3.5 kPa. However, when testing thin ones there was no statistically significant difference between the 3 values of contact pressure.

Influence of the Metallic Body contact surface roughness: An alternative surface was obtained by applying a certain texture to the steel. Results showed that this new surface gave, as expected, higher values of friction coefficient than the smooth one.

Comparison with KES-F: A very limited set of experiments showed that for the same fabric, values of Miu from KES consistently fall between those obtained with the two metallic surfaces, SMB and TMB from FRICTORQ. However, looking at the statistics, the CV% is 5.2% in KES and 1.7% with SMB and 1.2% with TMB in FRICTORQ.

7. Conclusions

The experimental work carried out so far has shown promising capabilities for the FRICTORQ principle and design. From the results obtained during the different phases of the project, the following conclusions can be drawn. 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.

SM 25 Standard Fabric gave higher values for Miu than our developed Smooth Metallic Body, and the latter gave more accurate results.

For the used values of contact pressure, the role of this parameter it is not absolutely clear. Yet only thick fabrics have shown some dependence only when 20 kPa was used. However, more research is needed to clarify this point in order to evaluate the influence of the fabric parameters.

Comparing values of Miu measured with the two equipments, those obtained with KES consistently fall between those obtained with the two metallic surfaces, SMB and TMB from FRICTORQ. Based on these results, it is clear that FRICTORQ shows capabilities of accessing friction in fabrics, with a smaller coefficient of variation than KES.

More research 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 granted [9].

Acknowledgements

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[9] Portuguese Patent N.º 102790, Inventors/authors: Mário Lima and Lubos Hes, Title: Método e Aparelho para a Determinação do Coeficiente de Atrito de Materias Sólidos Planos (Method and Instrument for the Measurement of the Coefficient of Friction in Flat Solid Materials), 12 June 2002

Appendix

Table 1 Identification of tested fabrics

Fabric reference	**80**	**90**	**100**
Material	Cotton	Cotton	Wool
Weight (g/m^2)	96,5	180,8	164,0
Processing stage	Finished	Finished	Finished
Fabric structure	Plain weave	Twill weave	Plain weave

Table 2 Identification of test conditions

Reference nº	**Test conditions**
82	Smooth Metallic Body, SMB, (Ø 28/24), 20 kPa
83	Smooth Metallic Body, SMB, (Ø 28/24), 10 kPa
84	Smooth Metallic Body, SMB, (Ø 28/24), 3,5 kPa
92	Smooth Metallic Body, SMB, (Ø 28/24), 20 kPa
93	Smooth Metallic Body, SMB, (Ø 28/24), 10 kPa
94	Smooth Metallic Body, SMB, (Ø 28/24), 3,5 kPa
100	KES-F friction
101	Smooth Metallic Body, SMB, (Ø 50/40), 3,5 kPa
102	Textured Metallic Body, TMB, (Ø 50/40), 3,5 kPa

Table 3 Statistical descriptives for different contact pressures with fabric 80

Test ref.	N	Mean µ Kin	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound.	Upper Bound.		
82	15	0,21487	0,04134	0,01067	0,19197	0,23776	0,139	0,282
83	13	0,20962	0,05908	0,01639	0,17392	0,24533	0,152	0,364
84	13	0,24672	0,04956	0,01374	0,21678	0,27667	0,163	0,310
Total	41	0,22330	0,05146	0,00804	0,20706	0,23955	0,139	0,364

Table 4 Statistical descriptives for different contact pressures with fabric 90

Test ref.	N	Mean µ Kin	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound.	Upper Bound.		
92	13	0,18575	0,02195	0,00609	0,17249	0,19902	0,142	0,232
93	13	0,24238	0,05113	0,01418	0,21549	0,27328	0,184	0,332
94	13	0,27506	0,05994	0,01663	0,23884	0,31128	0,183	0,378
Total	39	0,23440	0,05924	0,00949	0,21520	0,25360	0,142	0,378

Table 5 Multiple comparisons of the results for different contact pressures with fabric 80

(I) Test ref.	(J) Test ref.	Mean Difference (I-J)		Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
82	83	0,00524		0,01897	0,96257	-0,04309	0,05358
	84	-0,03186		0,01897	0,25679	-0,08019	0,01648
83	82	-0,00524		0,01897	0,96257	-0,05358	0,04309
	84	-0,03710		0,01964	0,18175	-0,08713	0,01293
84	82	0,03186		0,01897	0,25679	-0,01648	0,08019
	83	0,03710		0,01964	0,18175	-0,01293	0,08713
Any of the mean differences is significant at the 0,05 level.							

Table 6 Results from Scheffe statistical analysis for different contact pressures with fabric 80

Test ref.	N	Subset for alpha = 0,05
		1
83	13	0,209623077
82	15	0,214866667
84	13	0,246723077
Sig.		0,168496049

Table 7 Multiple comparisons of the results for different contact pressures with fabric 90

(I) Test ref.	(J) Test ref.	Mean Difference (I-J)		Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
92	93	-0,05663	*	0,01852	0,016	-0,10392	-0,00934
	94	-0,08931	*	0,01852	0,000	-0,13660	-0,04202
93	92	0,05663	*	0,01852	0,016	0,00934	0,10392
	94	-0,03268		0,01852	0,225	-0,07997	0,01946
94	92	0,08931	*	0,01852	0,000	0,04202	0,13660
	93	0,03268		0,01852	0,225	-0,1461	0,07997
* The mean difference is significant at the 0,05 level.							

Table 8 Results from Scheffe statistical analysis for different contact pressures with fabric 90

Test ref.	N	Subset for alpha = 0,05	
		1	2
92	13	0,18575	
93	13		0,24238
94	13		0,27506
Sig.		1	0,225

Table 9 Statistical descriptives for comparison between KES and FRICTORQ

Test ref.	N	Mean µ Kin	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound.	Upper Bound.		
100	19	0,23584	0,01235	0,00283	0,22989	0,24180	0,203	0,253
101	12	0,14383	0,00243	0,00070	0,14228	0,14537	0,139	0,147
102	12	0,32399	0,00384	0,00111	0,32155	0,32643	0,320	0,332
Total	43	0,23476	0,06862	0,01046	0,21364	0,25588	0,139	0,332

Table 10 Multiple comparisons of the results for comparison between KES and FRICTORQ

(I) Test ref.	(J) Test ref.	Mean Difference (I-J)		Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
100	101	0,09202	*	0,00318	0,00000	0,08393	0,10010
	102	-0,08815	*	0,00318	0,00000	-0,09623	-0,08007
101	100	-0,09202	*	0,00318	0,00000	-0,10010	-0,08393
	102	-0,18017	*	0,00352	0,00000	-0,18912	-0,17122
102	100	0,08815	*	0,00318	0,00000	0,08007	0,09623
	101	0,18017	*	0,00352	0,00000	0,17122	0,18912
* The mean difference is significant at the 0,05 level.							

Table 11 Results from Scheffe statistical analysis for comparison between KES and FRICTORQ

Test ref.	N	Subset for alpha = 0,05		
		1	2	3
101	12	0,143825		
100	19		0,235842	
102	12			0,323992
Sig.		1	1	1