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FRICTORQ, Mechatonic Design for the Objective Measurement of Friction in 2D Soft Surfaces

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ABSTRACT

The paper briefly describes a novel patented laboratory equipment, which was studied, designed and manufactured at the University of Minho based on a new method of accessing friction coefficient of fabrics and other 2D non-rigid surfaces, such as nonwovens and soft papers. Friction Coefficient is not an inherent characteristic of a material or surface, but results from the contact between two surfaces. Unlike other methods, FRICTORQ is based on a rotary movement and therefore on the measurement of a friction reaction torque. The contact between the sample and the instrument contact surface is restricted to 3 small surfaces disposed radially at 120°. With a relative displacement of approximately 90°, it is assured that a fresh portion of the sample is always moved under this surfaces. Friction coefficient is computed from the friction reaction torque measured by a high sensitivity torque sensor. The model went through various development stages and some of the detected weaknesses suggested that a different approach could be explored which developed into the latest adopted model named FRICTORQ II. A description of the instrument is given as well as its fundamentals and working principle followed by an experimental study, where the influence of the colour dye applied to napkins and handkerchiefs is performed. The results are analysed using various methods included in SPSS16.0® statistical package and commented on the light of the influence of these variables in the friction properties of the materials.

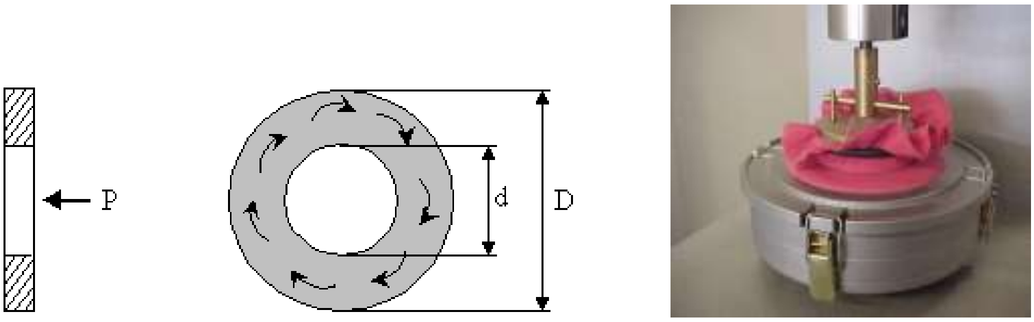
INTRODUCTION

The way human beings sense and interact with textile materials is closely related to their performance properties [1, 2], particularly in the case of those materials that are worn in contact with the skin, such as clothing, home textiles, furnishings and automotive fabrics. The importance of fabric coefficient of friction is confirmed by the number of scientific studies carried out in the past on this subject [3-7]. Recently, new laboratory equipment was proposed, based on a new method of assessing the friction coefficient of fabrics, which is easy to use and very precise. Several previous studies were performed in order to find a relationship between friction coefficient, as measured with FRICTORQ, and fabric friction properties measured by other instruments and other surface evaluations based on subjective assessments. It is possible to name the following: A comparative study with KES (Kawabata Evaluation System) friction [8] and another comparative study with fabric weave structure using subjective assessment [9]. All these studies have consistently led to the conclusion that higher fabric friction coefficient corresponds to smother surfaces. In the comparison with

KES it was also possible to notice that the dispersion of results was lower with FRICTORQ than with KES friction. The development and validation of FRICTORQ as reliable test equipment [10] justifies experimental work comparing the friction coefficient of different types of soft papers (tissue) used by humans in their everyday life.

THE FRICTORQ INSTRUMENT

The evolution of the FRICTORQ instrument is summarized in figures 1 and 2. It comprises a torque sensor with the respective data acquisition system, a DC motor with a cinematic chain (gears and timing belt) to drive the lower fabric sample, and software designed specifically for this application. This is a new method used by the authors to determine the coefficient of friction of textile fabrics and other 2D soft materials, based on the dry clutch principle, where an annular shaped flat upper body (kept still during the whole test procedure) rubs against a lower flat surface, which rotates around a vertical axis at a constant angular velocity.



(A) (B)

Figure 1: (A) Geometry of the first adopted theoretical model for the FRICTORQ I; (B) First developed FRICTORQ set-up: detail view of the positioning and tightening fabric clamps

Contact pressure is constant, given by the ratio between the own weight of the upper body and the contact area. The signal acquired by the torque sensor is digitalized through an electronic interface and fed into a PC where friction coefficient is computed. This first testing set-up, named FRICTORQ I, is highlighted in figure 1 [11, 12]. The principle is based on a ring shaped body rubbing against a flat surface as shown in the model of figure 1-A. 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, [13], 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

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

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.

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

This model went through various development stages and some of the detected weaknesses suggested that a different approach could be explored [14, 15]. Nevertheless the rotary action remained, but the contact is now restricted to 3 small special elements (feet), radially disposed at 120°. Providing a relative displacement of approximately 90°, it is assured that a new portion of fabric is always moved under these contact elements. Figure 2 is a schematic representation of the latest adopted model named FRICTORQ II.

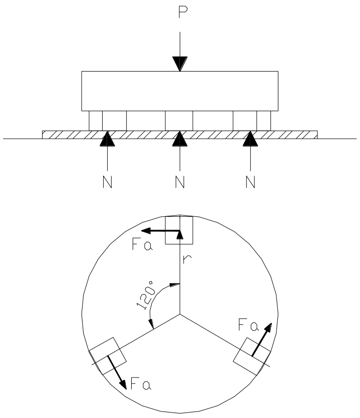


Figure 2: FRICTORQ II model

For this model, torque is given by:

$$T = 3\,F_a\,r \qquad (4)$$

Being, by definition, $F_a = \mu N$ and from figure 2, N = P/3, where *P* is the vertical load, the coefficient of friction is then expressed by:

$$\mu = \frac{T}{P \cdot r} \qquad (5)$$

The laboratory prototype of the instrument is represented in figure 3. 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. 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 3: FRICTORQ II laboratory prototype

Previous exploratory work led to the establishment of some design parameters, namely contact pressure and linear velocity in the geometric centre of each contact foot, the latter set to approximately 1,57 mm/s.

Figure 4 highlights the latest test set-up, as well as a detail of the upper body (or contact sensor) that includes 3 small pads with an approximately square shape, covered by a number of calibrated steel needles of 1 mm diametre.

(A) (B)

Figure 4: (A) FRICTORQ II; (B) The upper body (or contact sensor) with 3 small pads at 120º

Figure 5 represents a typical output display, showing the most relevant parameters acquired on a simple friction test. Data acquired between 5 and 20 seconds of the experiment was used for computing the kinetic or dynamic friction coefficient of the tested fabric samples.

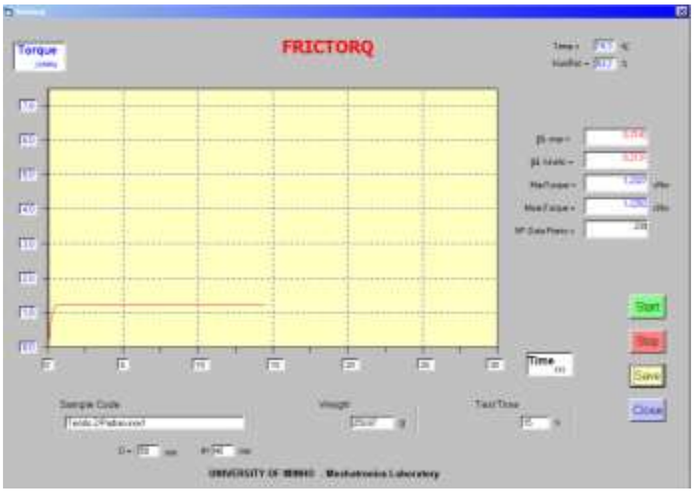


Figure 5: Typical output display of the instrument

METHODOLOGY

Friction tests were carried out using the instrument FRICTORQ II with contact sensor NB 3,5 (3,5 kPa of contact pressure) in a set of 8 paper samples produced by the Portuguese RENOVA Company, namely, 4 different coloured Facial Tissues (T) and 4 different coloured Napkins (N). Table 1 summarises the company references of all tested materials. For each of the materials, samples with 11,3 cm diametre were cut. All the tests were made under a standard atmosphere (20º C and 65% RH), and all the materials were conditioned for a time period over 24 hours. For each material 13 samples were tested. The obtained results were analysed using SPSS16® statistical package.

Results and discussion

For an easy visualization, the results for each of the analysed groups are presented in a graphical form using the box-plot representation. In the identification of the samples, **O** means outer face while **I** mean inner face. In table 1 are listed the materials used in this study.

Table 1 Identification of the materials

Paper	Colour	Inner face	Outer face
Facial Tissues	Black	Black_I_T	Black_O_T
	Orange	Orange_I_T	Orange_O_T
	Green	Green_I_T	Green_O_T
	Red	Red_I_T	Red_O_T
Napkins	Black	Black_I_N	Black_O_N
	Orange	Orange_I_N	Orange_O_N
	Green	Green_I_T	Green_O_T
	Red	Red_I_N	Red_O_N

Facial Tissues (T)

The results obtained in the tests carried out with FRICTORQ for the 8 Facial Tissues are graphically displayed in figure 6.

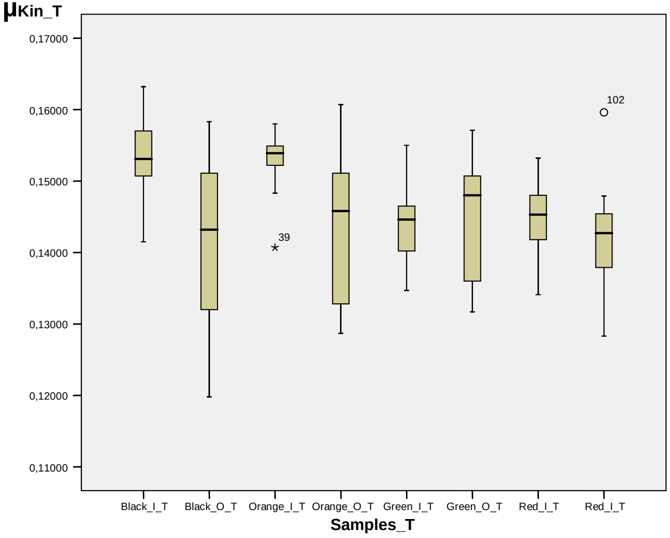


Figure 6: Box-plot for T samples

The obtained results as shown in the box-plot, clearly demonstrate that the higher amplitudes are in the outer faces for all samples, meaning a lower homogeneity of its surface. In the opposite situation, the inner faces have lower amplitudes.

In order to compare the results obtained from the 8 tested materials a Scheffe analysis was carried out as to determine the existence of homogeneous subsets. Means for groups in homogeneous subsets are displayed in table 2. It uses harmonic mean sample size = 13.

Table 2 Means for groups in homogeneous subsets for T samples

Samples_T	N	Subset for alpha = 0,05
		1
Black_O_T	13	0,141
Red_I_T	13	0,141
Green_I_T	13	0,144
Orange_O_T	13	0,144
Green_O_T	13	0,144
Red_I_T	13	0,145
Orange_I_T	13	0,153
Black_I_T	13	0,154
Sig.		0,057

The statistical analysis shows that the behaviour of these 8 samples is grouped in only one group, meaning that there is no significant statistical differences between all them.

Napkins (N)

The results obtained in the tests carried out with FRICTORQ for the 8 Napkins are graphically displayed in figure 7.

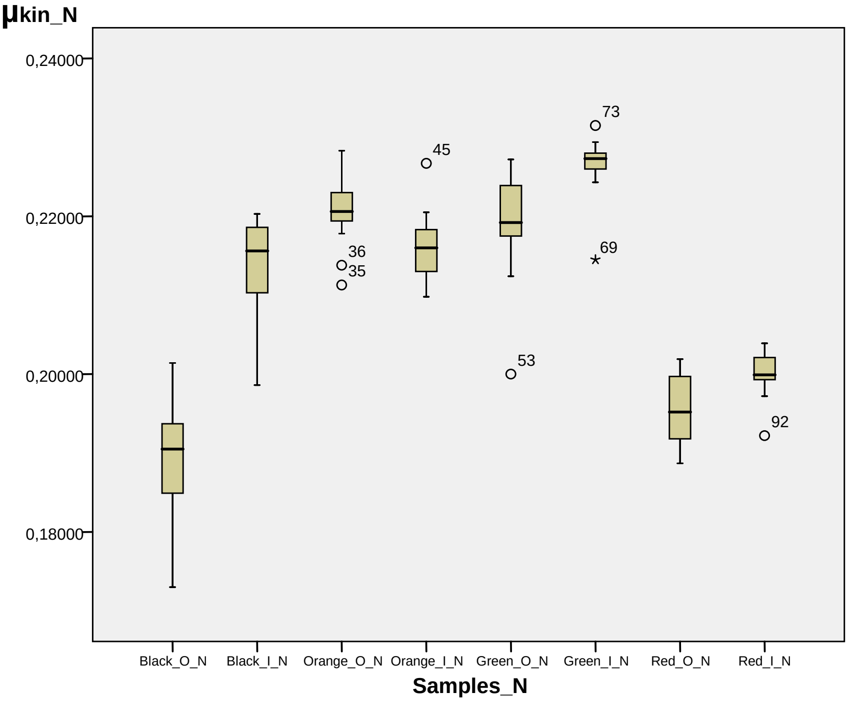


Figure 7: Box-plot for the N samples

The obtained results shown in the box-plot demonstrate that the behaviour of the inner and outer faces is similar, with higher friction on the inner face, except for the orange colour. No reason for this was found. It must be noticed that the black samples are the only ones with no outliers in the tests.

In order to compare the results obtained from the 8 tested materials a Scheffe analysis was carried out as to determine the existence of homogeneous subsets. Means for groups in homogeneous subsets are displayed in table 3. It uses harmonic mean sample size = 13.

The statistical analysis shows that the behaviour of this 8 samples are grouped in 4 different subgroups: The one formed by samples Black-O and Red-O, the second with Red-I and O, the third with Black-I, Orange-I and O and Green-O, and the last with Green-O, Orange-O and Green-I. There is a statistical significant difference between the results obtained with Black-O, Red-I, Orange-I and Green-I, meaning that the colour of the used dyestuff influences friction.

Table 3 Means for groups in homogeneous subsets

Samples_N	**N**	**Subset for alpha = 0,05**			
		1	2	3	4
Black_O_N	13	0,190			
Red_O_N	13	0,195	0,195		
Red_I_N	13		0,200		
Black_I_N	13			0,214	
Orange_I_N	13			0,217	
Green_O_N	13			0,219	0,219
Orange_O_N	13			0,221	0,221
Green_I_N	13				0,223
Sig.		0,619	0,559	0,174	0,081

In order to compare the values obtained for Facial Tissues and Napkins, a box-plot was made which is presented in figure 8. It is clear that friction for Napkins is always higher than for Facial Tissues.

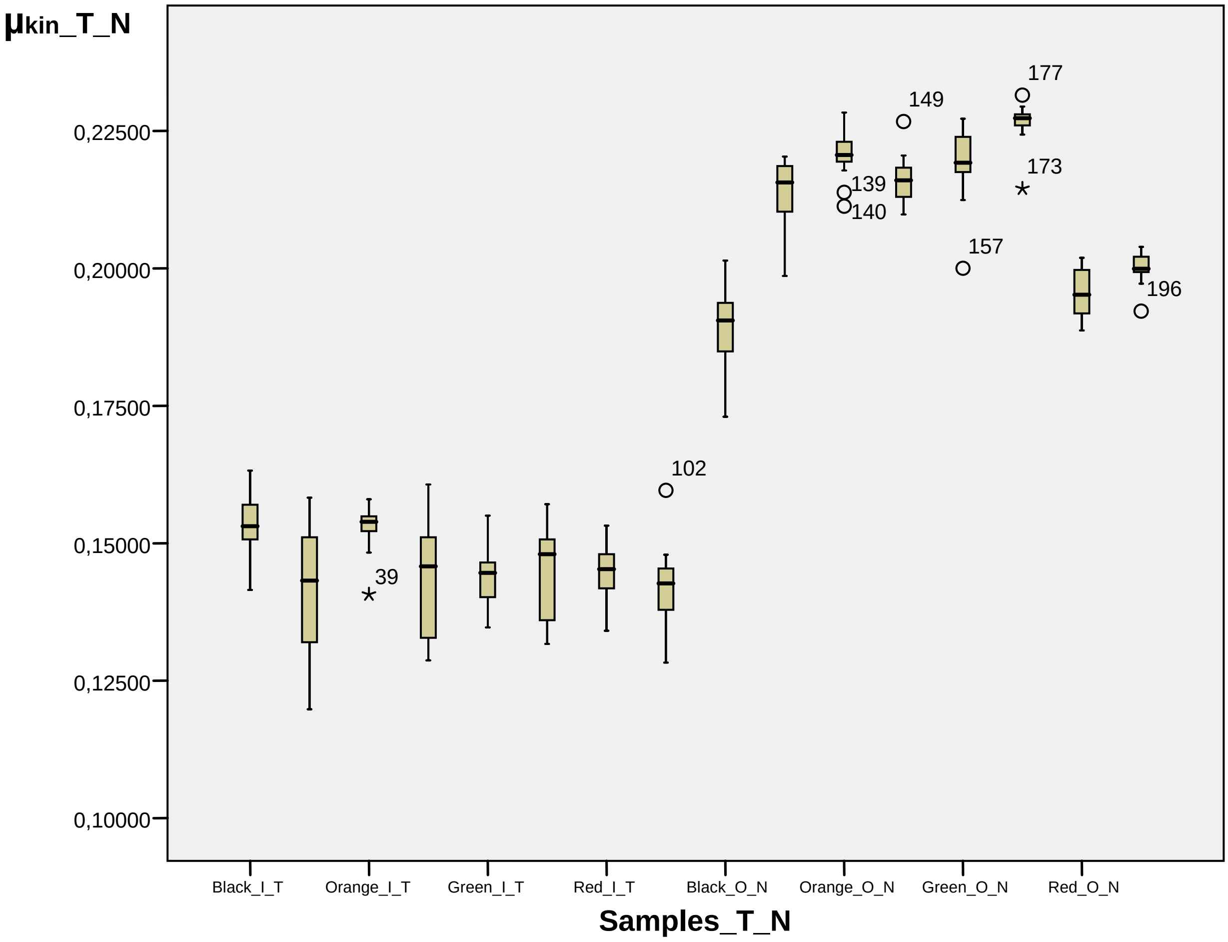


Figure 8: Box-plot for N and T samples

CONCLUSIONS

The results obtained show that FRICTORQ is technically simple and a reliable instrument to access surface properties of soft papers.

From the analysis of the obtained results it is possible to draw the following main conclusions:

For Facial tissues only one group was obtained in the statistical analysis, meaning that there are no differences between the colours of the dyestuffs used in the friction.

When comparing the four groups obtained for Napkins, the higher values are obtained for the Green one (0,226) and the lowest for the Black ones (0,190). In this case the colour of the used dyestuff influences the friction.

As a preliminary subjective evaluation, the samples which present the best fullness and softness are the Napkins while those with higher stiffness are the Facial Tissues. These results lead to the conclusion that higher friction values correspond to a smoother perception.

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