FRICTORQ, DESIGN FOR THE OBJECTIVE MEASUREMENT OF FRICTION IN 2D SOFT SURFACES

Mário Lima

Luís Ferreira da Silva

University of Minho, Department of Mechanical Engineering, Guimarães, Portugal

Rosa Vasconcelos

Joana Cunha

University of Minho, Department of Textile Engineering, Guimarães, Portugal

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.

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 special elements disposed radially at 120°. With a relative displacement of approximately 90°, it is assured that a new portion of the sample is always moved under the surface. Friction coefficient is computed from the friction reaction torque measured by a high sensitivity torque sensor.

In the paper, a description of the instrument is given as well as its fundamentals and working principle followed by an experimental study, where a comparison between different types of soft papers (tissue) was performed. The results are analysed using various tools, including SPSS16.0® statistical package and commented on the light of the influence of different specifications of the samples in the friction properties of the materials.

Keywords: Mechatronics design; Friction coefficient; Laboratory equipment; FRICTORQ.

Resumo

O artigo descreve de forma breve um equipamento laboratorial inovador e patenteado, que foi estudado, projectado e construído na Universidade do Minho, tendo por base um novo método para a determinação do coeficiente de atrito em tecidos e outras superfícies 2D não-rígidas.

O Coeficiente de Atrito não é uma característica inerente ao material ou superfície, antes resulta do contacto entre duas superfícies. Ao contrário de outros métodos, o FRICTORQ baseia-se num movimento rotativo e portanto na medição de um binário resistente de atrito. O contacto entre a amostra e a superfície de referência do instrumento é restrito a 3 pequenos elementos de contacto dispostos radialmente a 120°. Com um deslocamento relativo de aproximadamente 90°, garante-se que uma nova porção da amostra é utilizada durante o ensaio. O coeficiente de atrito é determinado a partir do binário resistente medido por um sensor de binário de alta sensibilidade.

No artigo é feita uma descrição do instrumento assim como os princípios e o modo de funcionamento, seguido de um estudo experimental onde é feita uma comparação entre

diferentes tipos de papéis delicados (tissue). Os resultados são analisados com recurso a várias ferramentas, incluindo o pacote estatístico SPSS16.0®, e comentados à luz da influência das diferentes especificações das amostras nas propriedades de atrito dos materiais.

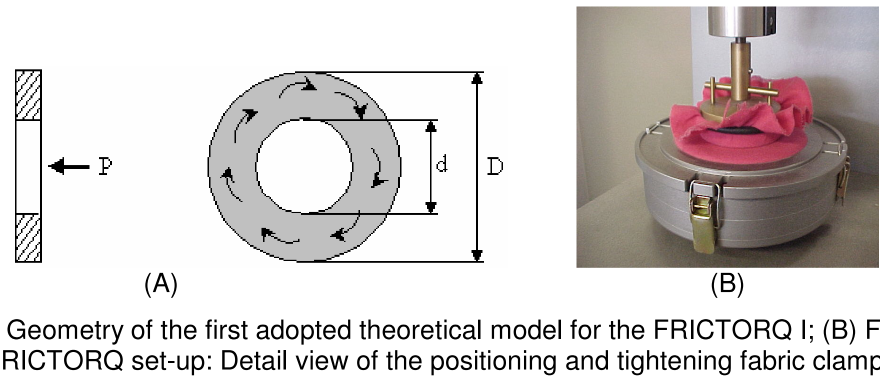
Palavras-chave: Projecto mecatrónico; Coeficiente de atrito; Equipamento laboratorial; FRICTORQ.

1. 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 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.

2. 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 a software package designed specifically for this application. This is a new method used by the authors to determine the coefficient of friction of textile fabrics, 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].

This model went through various development stages and some of the detected weaknesses suggested that a different approach could be explored. 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.

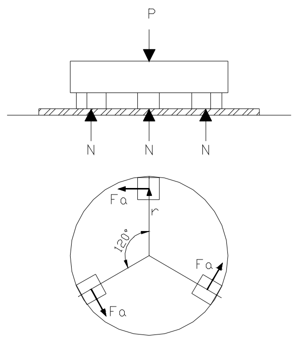


Figure 2 - FRICTORQ II model.

The laboratory prototype of the instrument is represented in figure 3. For the sake of completeness, it must be referred that the discussion of other models and further design details for the development of the present prototype have already been published elsewhere [13, 14].

Figure 3 - FRICTORQ II laboratory prototype.

For this model, torque is given by:

$$T = 3\ F_a\ r \tag{1}$$

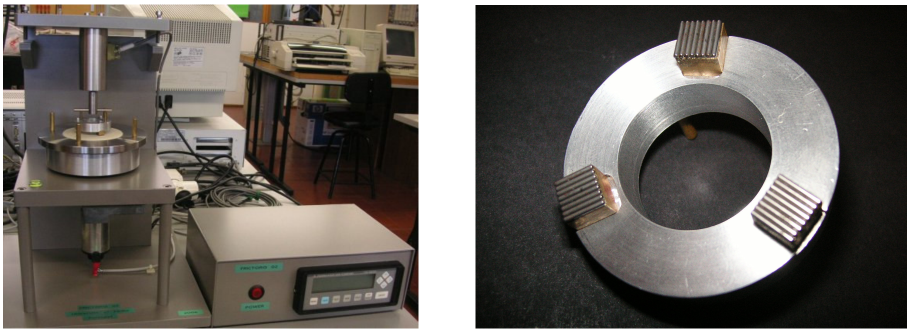
Being, by definition, $F_a = \mu N$ and from figure 1, $N = P/3$, where P is the vertical load, the coefficient of friction is then expressed by:

$$\mu = \frac{T}{P \cdot r} \tag{2}$$

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 diameter.

Figure 5 presents 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.



(A) (B)

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

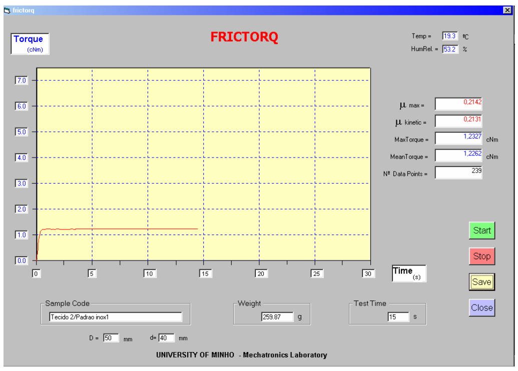


Figure 5 - Typical output display of the instrument.

3 Methodology

Friction tests were carried out using the instrument FRICTORQ NB 3,5 (3,5 kPa of contact pressure) in a set of 3 paper samples produced by the Portuguese RENOVA company, namely, toilet paper (pH), facial tissues (LF) and hand tissues (TM). Table 1 summarises company references of all tested materials.

For each of the materials, samples with 11,3 cm diameter were cut, except for the toilet paper where rectangular sections defined by the printed perforations were used as the rolls had a width less than 11,3 cm.

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 12 samples were tested. The obtained results were analysed using SPSS16® statistical package.

4 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 some of the samples, D means the outer face.

4.1 Toilet paper (pH)

The results obtained in the 12 tests carried out with FRICTORQ are graphically displayed in figure 6.

Material	Type
Toilet paper (pH)	pH 4FLS
	pH F&C
	pH RG XXL
	pH SUP
Hand tissues (TM)	TM SOFT
	TM 3FLS
	TM TCD
Facial tissues (LF)	LF KC
	LF 3FLS AM
	LF 2FLS mini

Table 1. Identification of materials.

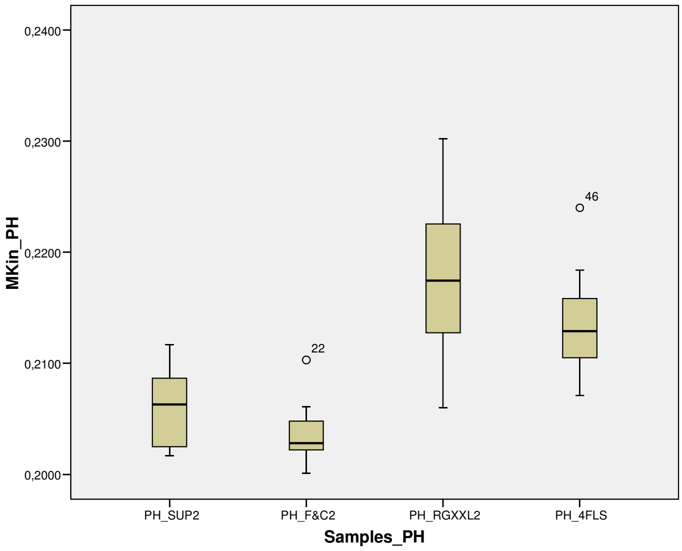


Figure 6 - Box-plot for pH samples.

The obtained results as shown in the box-plot, clearly demonstrate that sample PH_RGXXL2 has the higher amplitude, meaning a lower homogeneity of its surface. In the opposite situation, sample PH_F&C2 is the most homogeneous.

In order to compare the results obtained from the six 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 = 12.

Samples_PH	N	Subset for alpha = 0.05	
		1	2
PH_F&C2	12	0,204	
PH_SUP2	12	0,206	
PH_4FLS	12		0,214
PH_RGXXL2	12		0,218
Sig.		0,657	0,201

Table 2. Homogeneous subsets for PH samples (Scheffe).

The statistical analysis shows that the behaviour of this four samples are grouped in two different subgroups: The one formed by samples PH_F&C2 and PH_SUP2, which do not exhibit any significant statistical difference and the second, formed by samples PH_4FLS and PH_RGXXL2, also with no significant statistical difference.

A subjective preliminary evaluation was carried out in order to relate the obtained values with the materials smoothness. From these tests it resulted that samples PH_4FLS and PH_RGXXL2 were judged as smother than the others.

4.2 Facial tissues LF (LF)

The results obtained in the 12 tests carried out with FRICTORQ are graphically displayed in figure 7. As can be seen in figure 7, sample LFKC_D exhibits a much lower friction coefficient than the other two.

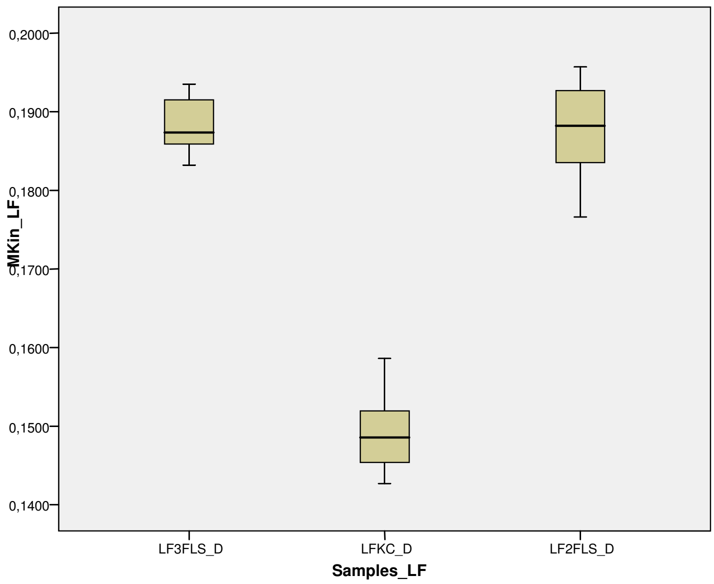


Figure 7 - Box-plot for LF samples.

A Scheffe analysis was carried out in order to compare the results obtained from the three tested facial tissues. Means for groups in homogeneous subsets are displayed in table 3. It uses harmonic mean sample size = 12.

The obtained results confirm that sample LFKC_D exhibits a clear difference from the other two analysed samples. The other two samples, LF2FLS and LF3FLS, do not show significant statistical difference between them related to friction.

Samples_LF	N	Subset for alpha = 0.05	
		1	2
LFKC_D	12	0,149	
LF2FLS_D	12		0,188
LF3FLS_D	12		0,188
Sig.		1,000	0,987

Table 3. Homogeneous subsets for LF samples (Scheffe).

Again, a subjective evaluation was performed for these samples from which the results of the perceived smoothness were consistent with the previous ones, meaning that the smoother samples are related to higher values of friction.

4.3 Hand tissues (TM)

Figure 8 depicts the results obtained in the 12 tests carried out with FRICTORQ. As can be seen, sample TM SOFT_D shows the higher amplitude of friction values, although the mean value is the lower. On the opposite, sample TM 3FLS_D presents the lower amplitude meaning a more homogeneous behaviour.

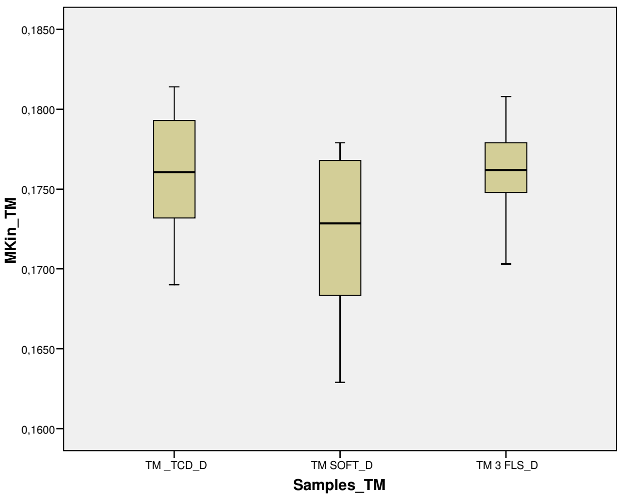


Figure 8 - Box-plot for TM samples.

A Scheffe analysis was carried out in order to compare the results obtained from the three tested hand tissues. Means for groups in homogeneous subsets are displayed in table 4. The obtained results show no significant statistical difference between all samples.

Samples_TM	N	Subset for alpha = 0.05
		1
TM SOFT_D	12	0,172
TM _TCD_D	12	0,176
TM 3 FLS_D	12	0,176
Sig.		0,096

Table 4. Homogeneous subsets for TM samples (Scheffe).

Following the methodology used in previous cases, a subjective evaluation was carried out for these samples resulting in no differences in the perceived smoothness.

5. Conclusions

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

For Toilet paper and Facial tissues different subgroups were obtained in the statistical analysis. This difference is due to the number of plies of each sample. The higher number of plies corresponds to higher values of friction coefficient.

When comparing the three sample groups Toilet paper (pH) presents the highest friction and Hand tissues (TM) the lowest. As to the preliminary subjective evaluation, the smoothest sample is the toilet paper (pH) while hand tissues are the roughest. This results lead to the conclusion that, for paper tissues, higher friction values correspond to a smoother perception.

References

[1] Kawabata, S., M. Niwa and F. Wang (1994), "Objective Hand Measurement of Nonwoven Fabrics", Textile Research Journal, Vol. 64, No. 10, October 1994.

[2] Gupta, B.S. and Y. E. El Mogahzy, (1991), "Friction in Fibrous Materials", Textile Research Journal, pp 547-555.

[3] Kawabata, S. (1980), "The Standardisation and Analysis of Hand Evaluation", 2nd. Ed., Textile Machine Society of Japan, 1980.

[4] Nosek, S. (1993), "Problems of Friction in Textile Processes", International Conference Textile Science 93, TU Liberec, Czech Republic.

[5] Bueno, M. A., M. Renner and B. Durand (1998), "Tribological Measurement of the State of Surface Fabrics by a Contact and a Non contact Method", Proceedings of the Conference Mechatronics'98, Sweden, pp 703-708.

[6] Behera, B. K., "Comfort and Handle Behaviour of Linen Blended Fabrics", AUTEX Research Journal, Vol. 7, No 1, March 2007, pp 33-47.

[7] Ramkumar, S. S., A. S.Umrani, D. C. Shelly, R. W. Tock, S. Parameswaran and M. L. Smith (2004), "Study of the Effect of Sliding Velocity on the Frictional Properties of Nonwoven Fabric Substrates", Wear, Vol. 256, Issues 3-4, February 2004, pp 221-225.

[8] Lima, M., Vasconcelos, R., Cunha, J., Martins, J., and Hes, L., FRICTORQ, Fabric Friction Tester: a Comparative Study with KES, Autex 2005, Portoroz, Slovenia (2005).

[9] Maria Inês Cabral Teles Borges de Araújo, Analysis of the Influence of the Weave Structure in the Friction Coefficient of Fabrics, Final Year Project, Apparel Engineering, University of Minho, Guimarães, Portugal (2006).

[10] Lima, M. and L. Hes (2002), Inventors/authors, Portuguese Patent Nº 102790, 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)", Date: 12th June 2002.

[11] Lima, M., Silva, L. F., Vasconcelos, R., Martins, J., and Hes, L., FRICTORQ, Tribometer for the Objective Evaluation of Textile Surfaces, III Iberian Congress of Tribology, IBERTRIB, University of Minho, Guimarães, Portugal (2005).

[12] Lima, M., Vasconcelos, R., Silva, L. F., and Martins, J., FRICTORQ, Innovation in the Objective Measurement of Friction in Textiles and Paper, Revista Nova Têxtil 78, 39–44 (2006).

[13] Lima, M., Hes, L., Vasconcelos, R., and Martins, J., FRICTORQ, Accessing Fabric Friction with a Novel Fabric Surface Tester, AUTEX Res. J. 5(4), 194–201 (2005).

[14] Lima, M., Hes, L., Vasconcelos, R., and Martins, J., FRICTORQ, a Novel Fabric Surface Tester: a Progress Report, J. Textile Eng. 51(3/4), 40–46 (2005).

Correspondence

For more information please contact with:

Prof. Mário Lima
Universidade do Minho, Departamento de Engenharia Mecânica
4800-058 GUIMARÃES (Portugal)
mlima@dem.uminho.pt