COMPARATIVE STUDY OF FRICTION COEFFICIENT IN NONWOVENS USING FRICTORQ, FABRIC FRICTION TESTER

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ABSTRACT

Nonwoven single-use surgical gowns are used and frequently touched by the human skin. Interaction with human senses is therefore an important performance property. When touched by the human hand, friction is one of the first feelings and therefore friction coefficient is an important parameter. Recently, a patented laboratory instrument was investigated and designed at the University of Minho based on an innovative method of accessing friction coefficient of 2D surfaces (fabrics, nonwovens, soft papers). Unlikely other methods, FRICTORQ is based on a rotary movement and therefore on the measurement of a friction reaction torque. On the more recent version the contact between the 2D sample and the instrument contact sensor is restricted to 3 small special elements radially disposed at 120°. Providing during the test a relative displacement of approximately 90°, it is assured that a new portion of the sample is always moved under the sensors. In the model, friction coefficient is worked out from the friction reaction torque measured by means of a high sensitivity torque sensor, the normal load created by the contact sensor and a geometrical parameter. Contact pressure on the fabric samples was set to 3,5 kPa and the linear velocity in the geometric centre of each contact element was approximately 1,5 mm/s. In the paper, a description of the instrument is given as well as its fundamentals and working principle followed by a study, where a comparison between three different materials for manufacturing medical gowns was performed under controlled atmosphere. The tested materials were materials were two Spunlace nonwoven and one SMS.

The results of the experimental work are analysed using various tools, including SPSS14.0® statistical package and discussed on the light of the importance of friction to the performance of surgical gowns.

Differences in friction coefficient were detected associated to the manufacturing process, composition of the nonwoven materials and outer or inner-faces.

1. INTRODUCTION

Interaction with the human senses is an essential performance property (Kawabata et al., 1994) and (Gupta, Mogahazy, 1991) as most textile materials are used near the skin, namely clothing, home furnishings and automotive fabrics. Friction coefficient is one of the factors contributing for the so-called parameter *fabric hand* and its importance justifies the number of contributions given in the past to this problem (Kawabata, 1980) and (Bueno et al., 1998). More recently, novel laboratory equipment was proposed for a new method of accessing the friction coefficient of fabrics which is easy to use, very precise and should be available at an acceptable cost. The development and validation of FRICTORQ (Lima at al, 2002) justifies an experimental work with a set of nonwoven fabrics used to manufacture single-use surgical gowns.

THE MODEL

2.1 FRICTORQ I

Friction Coefficient is not an inherent characteristic of a material or surface, but results from the contact between two surfaces (Nosek, 1993). 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.

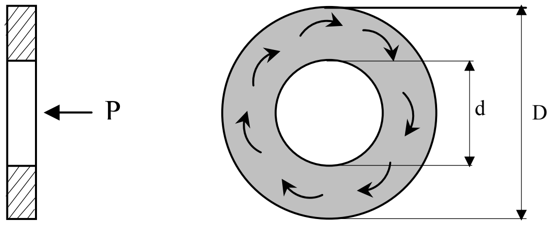


Fig. 1 - Geometry of FRICTORQ I model

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, (Phelan, 1970), 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.

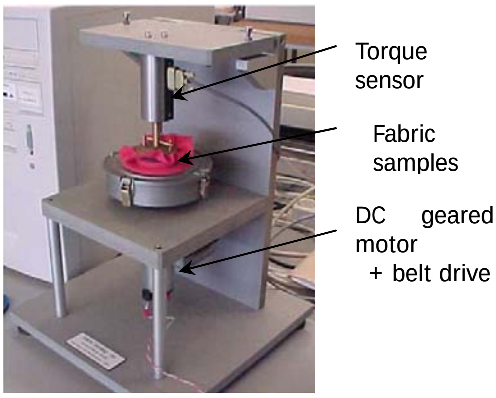
$$p = \frac{P}{A} = \frac{4.P}{\pi.(D^2 - d^2)} \qquad (2)$$

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.

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

2.1.1 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.



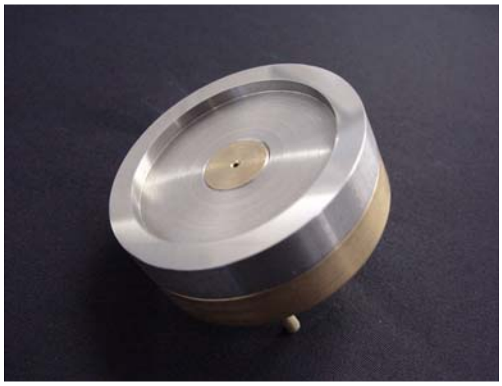


Fig. 2 - FRICTORQ I Laboratory prototype   Fig. 3 - Standard Metallic body

Figure 2 is a general view of FRICTORQ I. 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. Figure 3 is a metallic contact sensor, based on the FRICTORQ I model, made of polished stainless steel.

2.1.2 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, which 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. To compute the dynamic friction coefficient, data from the first 10 seconds of the process is ignored to allow the signal to stabilize. 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.

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

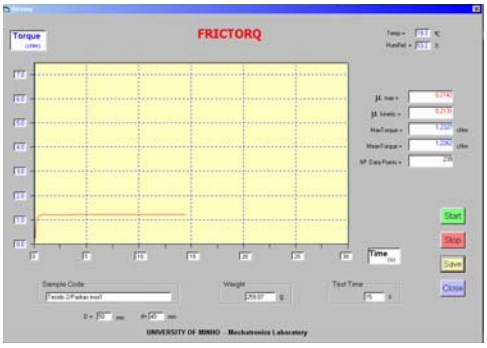


Fig. 4b - Graphic output for Steel-to-fabric

2.2 FRICTORQ II

This model went through various development stages, and some of the detected weaknesses suggested that a different approach could be explored (Mário Lima et al., 2005-a) and (Mário Lima et al., 2005-b). Figure 5 is a schematic representation of the new model. The rotary action remains, but the contact is now restricted to 3 small special elements disposed at 120°. Providing a relative displacement of approximately 90°, it is assured that a new portion of fabric is always moved under the contact sensors. For this model, Torque is given by:

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

Being, by definition, $F_a = \mu N$ and from Fig.5, $N = P/3$, where P is the vertical load, the coefficient of friction is expressed by equation 5,

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

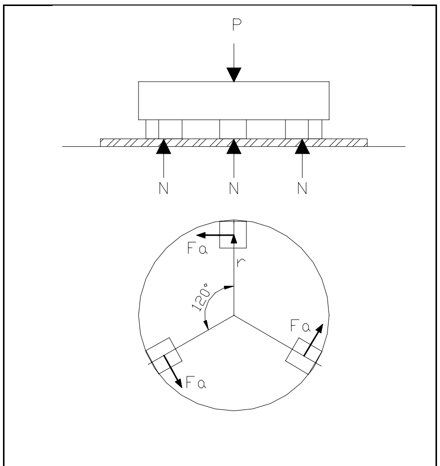


Fig.5 - FRICTORQ II model

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.

3. EXPERIMENTAL PROCEDURE

3.1 Characterisation of the Tested Materials

Nonwovens are the most commonly used textiles in U.S. operating rooms, employed in over 80% of all surgical procedures. Surgical personnel continue to indicate that the mayor reasons for using nonwovens include convenience of use, superior barrier properties and improved surgical productivity (Marques Abreu et al, 2000).

Novel nonwoven manufacturing technologies have been developed aimed at combining the functional properties with good aesthetics and comfort. Water-jet entanglement process for instance spunlace and composite nonwoven structures such as SMS, result in drapable materials, which have received a high degree of consumer acceptance (Avril et al, 2000).

Most spunlace products are composed of half cellulose, which provide fluid barrier and half polyester, which provide strength (45% PES/55% CO or 55% PES/45% CO). The hydroentangling process eliminates the need for adhesives or binders, which sometimes introduce unwanted chemicals into the product. This nonwoven corresponds to 55% of the american market (Lutolf, 1999).

Hydroentagled fabrics are consolidated by the action of water jets, forming ridges on the fabric surface. Fabrics are more compact and the ridged surface increases the fabric surface area. Machine settings such as the density of water jets, the force of the water jet, the speed at which the fabric is passed under them and the belt geometry all affect fabrics characteristics. In the hydroentaglement process, some shrinkage occurs, fabrics are more compact and fabric voids are reduced and resultant fabric area densities are increased (Abreu, 2004).

SMS fabrics are produced through an extrusion process and typically composed of polypropylene fibers (100% PP). The meltblown short fiber center provides fluid barrier and is sandwiched between two spunbond layers that provide the fabric strength. This process often results in higher barrier properties based on certain tests, however, the aesthetics are sometimes less desirable since this product is plastic based. This fabric is also well accepted in the marketplace and corresponds to 35 % of the american market share (Lutolf, 1999). Polypropylene has an increase in tensile and abrasion resistance but with a corresponding decrease in fabric softness compared with the spunlace products.

3.2 **Methodology**

The tested materials were nonwoven fabrics used for manufacturing single-use surgical gowns. Three different types have been studied:

1) 45% polyester/ 55% cellulose, 70 g/m^2, 0,35 mm, Spunlace nonwoven, coded as SL45PES-55CO;
2) 55% polyester/ 45% cellulose, 70 g/m^2, 0,35 mm, Spunlace nonwoven, coded as SL55PES-45CO;
3) 100% polypropylene, 35 g/m^2, 0,29 mm, coded as SMS-PP.

FRICTORQ II was used to test the surface of the three nonwoven materials in the outer-face (OF) and inner-face, (IF). Samples were prepared and cut in circles of 130 mm diameter and tested under a conditioned atmosphere.

4. RESULTS AND DISCUSSION

For each material 13 samples where tested. The results of the tests are represented in graphic form in figures 6 and 7.

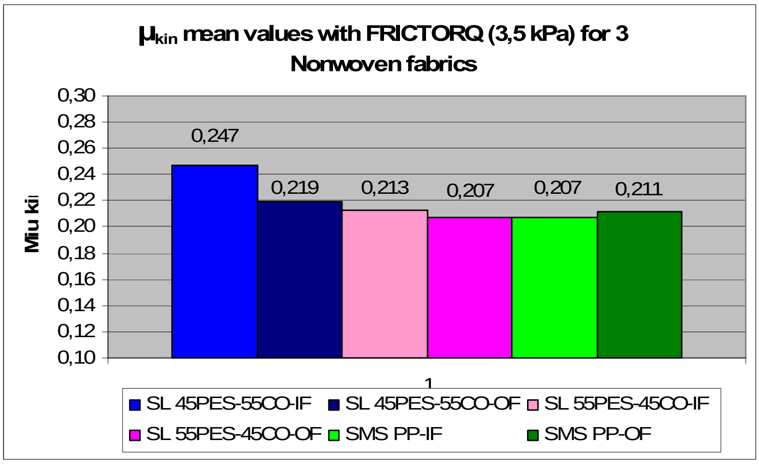


Fig. 6 - μ_{kin} mean values with FRICTORQ (3,5 kPa) for 3 nonwoven fabrics

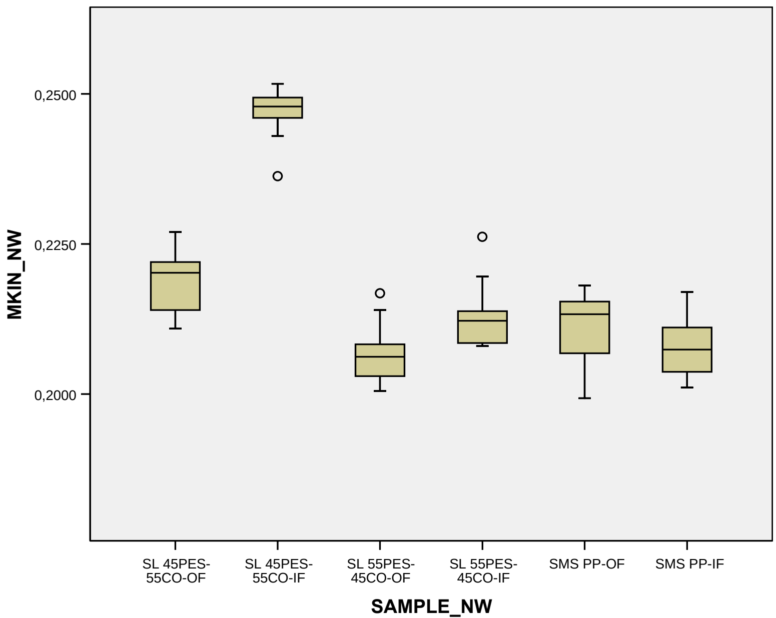


Fig.7 - Box-plot of results for all nonwoven samples

Data was analysed with SPSS (version 14.0 for Windows). Figure 7 is the graphical representation of the box plot obtained for the analysed samples. In this figure it can be seen that the dispersions of the box plots for almost all the samples tested in outer-face is larger than those tested in the inner-face. The SL45PES-55CO-IF gave the highest friction value.

In order to confirm the normal distribution of the data a Test of Homogeneity of Variances was carried out. The Value obtained is represent table I

Table I- Test of Homogeneity of Variances of MKIN_NW

Levene Statistic	df1	df2	Sig.
0,869	5	72	**0,506**

Table II- Statistical differences in Nonwoven Samples

	SL 45PES-55CO OF	SL 45PES-55CO IF	SL 55PES-45CO OF	SL 55PES-45CO IF	SMS PP OF	SMS PP IF
SL 45PES-55CO-OF		X	X		X	X
SL 45PES-55CO-IF	X		X	X	X	X
SL 55PES-45CO-OF	X	X				
SL 55PES-45CO-IF		X				
SMS-PP-OF	X	X				
SMS-PP-IF	X	X				

Table II represents the statistical differences (X) found between the tested samples. It is clear a significant difference between sample SL45PES-55CO and the other samples as well as the difference between the two faces. From the analysis of table III it can be seen that SL45PES-55CO-IF is statistically different from all the other tested samples.

Table III- Means for Nonwoven structures

Scheffe

SAMPLE_NW	N	Subset for alpha = .05		
		1	2	3
SL 55PES-45CO-OF	13	0,2069		
SMS PP-IF	13	0,2074		
SMS PP-OF	13	0,2111		
SL 55PES-45CO-IF	13	0,2130	0,2130	
SL 45PES-55CO-OF	13		0,2188	
SL 45PES-55CO-IF	13			**0,2470**
Sig.		0,1090	0,1350	1,000

Means for groups in homogeneous subsets are displayed

5. CONCLUSIONS

Based on the obtained results and the statistical analysis it is possible to draw the following conclusions:

1. The percentage of cotton used in the hydroentangled process (SL) influences the

coefficient of friction. The increasing of cotton percentage raises the friction coefficient.

2. Although two different nonwoven processes (SL and SMS) were studied, no statistical differences could be found between them.

3. The inner and outer faces results depend of the process used. Higher coefficients of friction in the inner faces are found in the hydroentangled process (SL) in opposition to those obtained by the SMS process.

4. FRICTORQ measurements suggest that its results could be used as a comfort parameter since information related with tactile perception is obtained.

6. REFERENCES

Abreu, Maria José (2004), "Contribuição para o Estudo da Parametrização de Têxteis Hospitalares", (*Contribution for the Study of the Parametrisation of Hospital Textiles*), Guimarães, Universidade do Minho, June 2004, Doctoral Thesis in co-supervision with the Université d´Haute Alsace, France.

Avril, R., Filmer, K. (2000), "Increased Understanding and Improvement in the Manufacture and Testing of Spunbond & Spunbond Composites resulting in Enhanced Fabric Properties", proceedings of the FiberMed Conference, Tampere, Finland, June 2000, pp. 42-53.

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

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

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

Mário Lima, Lubos Hes, Rosa Vasconcelos, Jorge Martins (2005-a), "FRICTORQ, Accessing Fabric Friction with a Novel Fabric Surface Tester", AUTEX Research Journal, Vol. 5, No 4, December 2005, pp 194-201.

Mário Lima, Lubos Hes, Rosa Vasconcelos, Jorge Martins (2005-b), "FRICTORQ, a Novel Fabric Surface Tester: a Progress Report", Journal of Textile Engineering, The Textile Machinery Society of Japan, Volume 51, No 3/4 (2005), pp 40-46.

Lutolf, P. E., (1999), "Wear and Laboratory Testing - OR Gowns Comfort Properties of Spunlace Nonwovens vs. Cotton Woven Fabrics", proceedings of the Index 99 Congress, Medical Session, Geneva, Switzerland, April 1999, 11 p.

Marie-Ange Bueno, Marc Renner, Bernard 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.

Mário Lima and Lubos 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.

Marques Abreu, M.J., Cabeço-Silva, M.E., Schacher, L., Adolphe, D.C. (2000), "The Influence of the Sterilisation in the Balance between Comfort vs. Barrier Properties of Surgical Protective Clothing", proceedings of the FiberMed Conference, Tampere, Finland, June 2000, pp. 146-155.

Nosek, S. (1993), "Problems of Friction in Textile Processes", International Conference TEXTILE SCIENCE 93, TU Liberec, Czech Republic, 1993.

Phelan, Richard M., "Fundamentals of Mechanical Design", 3rd Edition, McGraw-Hill Book Company, 1970, pp 267-270.

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