

COMPARATIVE STUDY OF FRICTION COEFFICIENT IN NONWOVENS APPLIED FOR NON ACTIVE MEDICAL DEVICES

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ABSTRACT

Surgical gowns are considered non active medical devices. They can be single-use or reusable and during an operation they are in constant contact with the human skin. Interaction with the 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. A patented laboratory instrument was designed at the University of Minho based on an innovative method of accessing friction coefficient of 2D surfaces (fabrics, nonwovens, soft papers). Unlike other methods, the instrument FRICTORQ is based on a rotary movement and therefore on the measurement of a friction reaction torque. A short description of the FRICTORQ instrument will be given as well as its fundamentals and working principle followed by a study, where a comparison of the coefficient of friction between three different materials for manufacturing surgical gowns was performed. The tested materials were two Spunlace nonwovens and one SMS (spunlaid-meltblowing-spunlaid).

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.

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

Key Words: Non Active Medical Devices, Surgical gowns, Nonwoven, Frictorq, Friction coefficient.

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1. INTRODUCTION

Interaction with the human senses is an essential performance property (1, 2) and as most textile materials 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 (3, 4).

Recently, laboratory equipment was proposed for a new method of accessing the friction coefficient of fabrics,

being easy to use and very precise. The development and validation of FRICTORQ (5) justifies an experimental work with a set of nonwoven fabrics used to manufacture non active medical devices (single-use surgical gowns).

2. TEST EQUIPMENTS

2.1 The FRICTORQ I Model

Friction Coefficient is not an inherent characteristic of a material or surface, but results from the contact between

two surfaces (6). 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.

The principle is based on a ring shaped body rubbing against a flat surface as shown in the model of Figure 1.

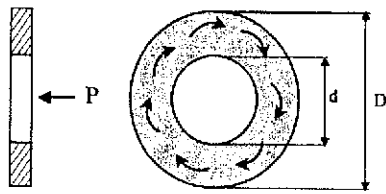


Figure 1. Geometry of FRICTORQ I model (5)

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 weight of the upper element and contact area. In this model, torque, T , is given by equation 1 (7), 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.

$$T = 2 \cdot \pi \cdot \mu \cdot \int_{d/2}^{D/2} p \cdot r^2 \cdot dr \quad [1]$$

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.

$$p = \frac{P}{A} = \frac{4 \cdot P}{\pi \cdot (D^2 - d^2)} \quad [2]$$

$$\mu = \frac{3 \cdot T \cdot D^2 - d^2}{P \cdot D^3 - d^3} \quad [3]$$

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.

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 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.

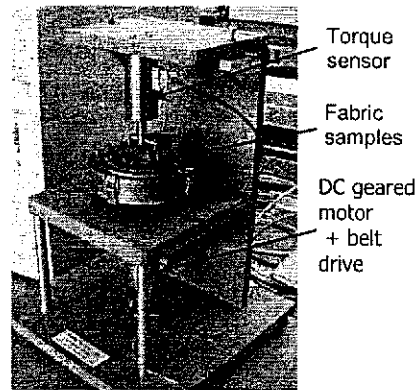


Figure 2. FRICTORQ I Laboratory prototype

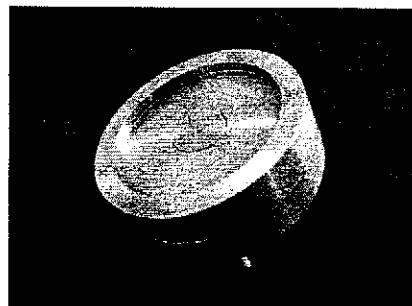


Figure 3. Standard Metallic body

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 centred over the lower one by means of a centring 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, μ_{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.

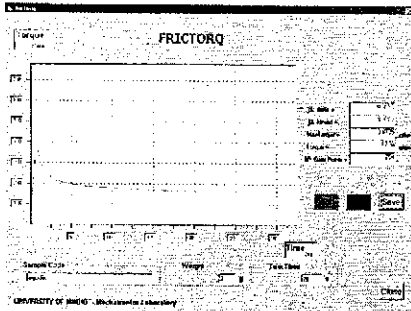


Figure 4a. Graphic output for fabric-to-fabric

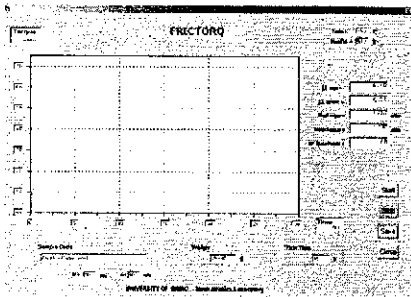


Figure 4b. Graphic output for steel-to-fabric

2.2 The FRICTORQ II Model

This model went through various development stages, and some of the detected weaknesses suggested that a different approach could be explored (8,9). Figure 5 is a schematic representation of the new model.

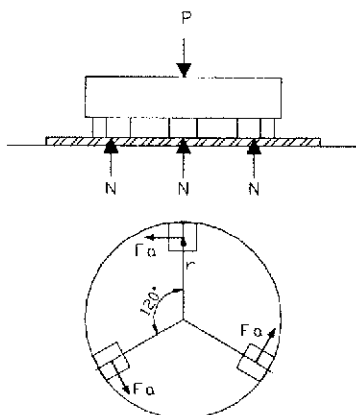


Figure 5. FRICTORQ II model (5)

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:

$$T = 3 F_a r \quad [4]$$

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,

$$\mu = \frac{T}{P \times r} \quad [5]$$

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. MATERIALS AND METHODS

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 major reasons for using nonwovens include convenience of use, superior barrier properties and improved surgical productivity (10).

Novel nonwoven manufacturing technologies have been developed aimed at combining the functional properties with good aesthetics and comfort. Water-jet entanglement process (spunlace) and composite nonwoven structures (such as SMS), result in drapable materials which have received a high degree of consumer acceptance, regarding comfort parameters (11).

Most spunlace products are composed of half cellulose, which provides fluid barrier and half polyester, which provides strength (45% PES/55% CO or 55% PES/45% CO). The hydroen-

tangling process eliminates the need for adhesives or binders, which sometimes introduce unwanted chemicals into the product. This nonwoven corresponds to 55% of the North American market (12). 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 hydroentanglement process, some shrinkage occurs, fabrics are more compact and fabric voids are reduced and resultant fabric area densities are increased (13).

SMS fabrics are produced through an extrusion process and typically composed of polypropylene fibres (100% PP). The meltblown short fibre centre 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 (12). 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% wood pulp, 70 g/m², 0,35 mm, Spunlace nonwoven, coded as SL45PES-55CO;
2. 55% polyester/ 45% wood pulp, 70 g/m², 0,35 mm, Spunlace nonwoven, coded as SL55PES-45CO;

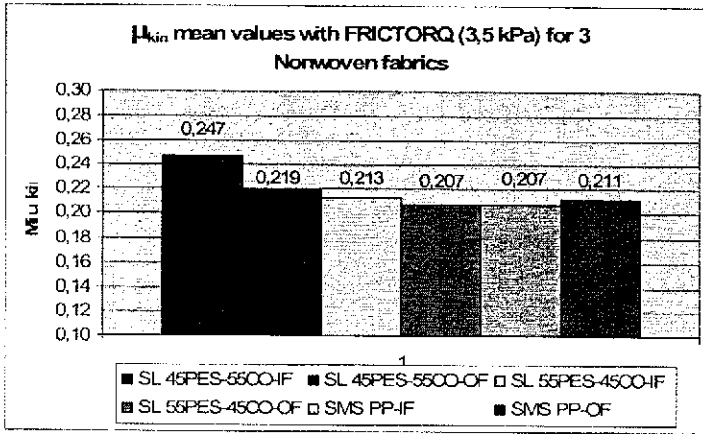


Figure 6. μ_{kin} mean values with FRICTORQ (3,5 kPa) for 3 nonwoven fabrics considering the Inner Face (IF) and Outer face (OF)

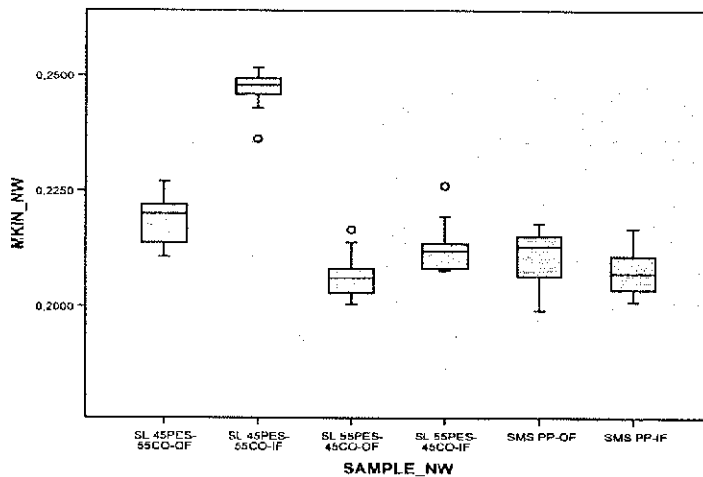


Figure 7. Box-plot of results for all nonwoven samples

Table 2. 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 3. Means for Nonwoven structures

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

3. 100% polypropylene, 35 g/m², 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) resulting in a total of 6 different measurements.

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 were tested. The results of the tests are represented in graphic form in figures 6 and 7.

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 are 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 represented in Table 1.

Table 1. Test of Homogeneity of Variances of μ_{kin}

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

In order to compare the results obtained a Scheffe analysis was carried out. Table 2 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 3 it can be seen that SL45PES-55CO-IF is statistically different from all the other tested samples.

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.

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