METROLOGICAL EVALUATION OF A MEASUREMENT SYSTEM OF THE COEFFICIENT OF FRICTION OF CERAMIC FLOOR TILES

Ueno, O.K.(*) ; Gonçalves, JR., A. A. (*) ; Alarcón, O. E. (**) ; Werncke, A.S.W.(***)

Universidade Federal de Santa Catarina (UFSC)
Departament of Mechanical Engineering
Laboratório de Metrologia -LABMETRO(*)
Laboratório de Materiais - LABMAT(**)
Centro de Tecnologia em Cerâmica -CTC(***)
Estado de Santa Catarina - Brazil

ABSTRACT

The present work sets out the results of an analysis performed from a metrological standpoint of the TORTUS measurement system, which was divided and assessed by modules. Module I consisted of the force measurement system and Module II comprised the signal acquisition card system, including the calculation programme. The uncertainties were evaluated by using the ISO standard Guide to the Expression of Uncertainty in Measurement (ISO GUM). Various sources of uncertainty associated with the procedure for characterising the dynamic coefficient of friction and the measurement system itself were analysed, and their influence quantified by means of controlled experiments. Calibrations were run on the signal acquisition modules (A/D) by means of a standard signal generator (mV), and on the force measurement system (TORTUS) by a standard mass. The evaluations of the uncertainty sources of the measurement process were determined using a smooth, flat reference surface. Typical commercial ceramic floor tile surfaces were also assessed. The results from the experiments include the following: critical aspects in the dry and wet measurements, levels of uncertainty usually found, and recommendations for optimising the metrological performance of the Tortus system for characterising the dynamic coefficient of friction of ceramic flooring.

1. INTRODUCTION

Slip can be defined as an intense drop in the value of the coefficient of friction between a body in motion and the supporting surface, occurring abruptly. The slip event can be defined as the loss of equilibrium owing to sudden, unexpected, uncontrolled foot movement, usually the final product of an inadequate coefficient of friction. For a even better understanding of the phenomenon it would be necessary to go into biomechanical concepts such as: individual gait, posture and knowledge of the coefficient of slip. The present study will just focus on the concepts of the coefficient of friction.

DEFINITION OF THE COEFFICIENT OF FRICTION

The first approach to friction suggests a force acting against a movement event on a body in space. Physically its existence has been explained in terms of the position of a body in space, and mainly of the variation in body speed in the existing motion with the arising speed developed by the body.

Two coefficient of friction concepts are currently defined, the static and dynamic coefficients of friction. The definition of the static coefficient of friction (μ_e) is the relation between a limiting friction (F_t) and the reaction normal to the plane supporting the body (F_n). The dynamic coefficient of friction (μ_d) is defined analogously to the static coefficient of friction in terms of the existence of a kinetic friction force (F_c), and is defined as the force that arises in the body interface with the supporting surface (F_n). Thus, on starting the motion, the intensity of the force is less than the force of static friction.

$$\mu_{e(d)} = \frac{F_{t(c)}}{F_n}$$

SURFACE INTERACTIONS

At the start of the 20th century, new research was conducted on the phenomenon of friction, which yielded a series of contributions. Studies of the coefficient of friction in rubbers indicated that these materials did not obey the friction laws, but exhibited peculiar behaviour. The coefficient of friction varied in terms of velocity.

Experiments have confirmed these findings. They also concluded that the rubber coefficient of friction depended on many factors such as: surface contact time and surface viscoelastic behaviour. In the field of viscoelasticity studies, the coefficient of friction (μ) between two surfaces can be defined as the sum of an adhesion component F_a added to another strain component F_d.

$$\mu = F_a + F_d$$

INFLUENCE OF CONTAMINANTS

Beyond the above-mentioned intrinsic factors, associated with human motion, other factors associated with the environment and contact surface conditions considerably affect slip, such as type of surface, hardness, load applied to the foot, relative velocity and the presence of surface contaminants such as liquid viscosity and surface tension.

The influence of contaminants is an important factor in modifying slip behaviour, from the gait posture to the reduction in the surface coefficient of friction with the presence of water, ice, grease or oil, making tiles with satisfactory properties become unsafe and dangerous for users. Under these conditions, increases in the relative velocity of motion produce a sharp drop in effective contact between the surfaces, raising slip risk.

It is important to consider surfaces with high roughness, as they permit contaminating material to be deposited in the valleys of the microscopic profile, encouraging contact points between the surface. Analysis of non-slip surface parameters also needs to include variables such as roughness, type of contaminating material and footwear. However, it is in the wet condition that ceramic surfaces are at a disadvantage, and their behaviour is clearly unfavourable in this situation.

2. CHARACTERISATION OF SLIPPERINESS IN CERAMIC TILES

ISO technical committee ISO/TC 189 has prepared ISO standard ISO 10545, which sets out the methods for determining ceramic tile characteristics according to ISO 13006. ISO 10545 is divided into 17 parts, each corresponding to a specific test. The part on the test method for characterising slip resistance is part no. 17, ISO 10545-17- Determination of the coefficient of friction. This study deals with "Method A" for the measurement of the dynamic coefficient of friction.

METHOD A - DETERMINATION OF THE DYNAMIC COEFFICIENT OF FRICTION

The system analysed in depth in this study was developed by British Ceramic Research for the determination of the dynamic coefficient of friction, known as the TORTUS system. The system fits Method A of ISO 10545-17 perfectly. In Brazil it is found as ABNT 13818 - Annex N.

The apparatus has four wheels and runs at a constant velocity of 17mm/s. A rubber slider in contact with the surface, fitted with a force-transducing measurement system, simulates foot movement. A constant vertical load of 2.0 N is set on parallel leaf springs on the slider, and moves horizontally over the test surface.

An inductive transducer probe (LVDT) converts the mechanical signals to electrical ones, producing a signal proportional to the friction force

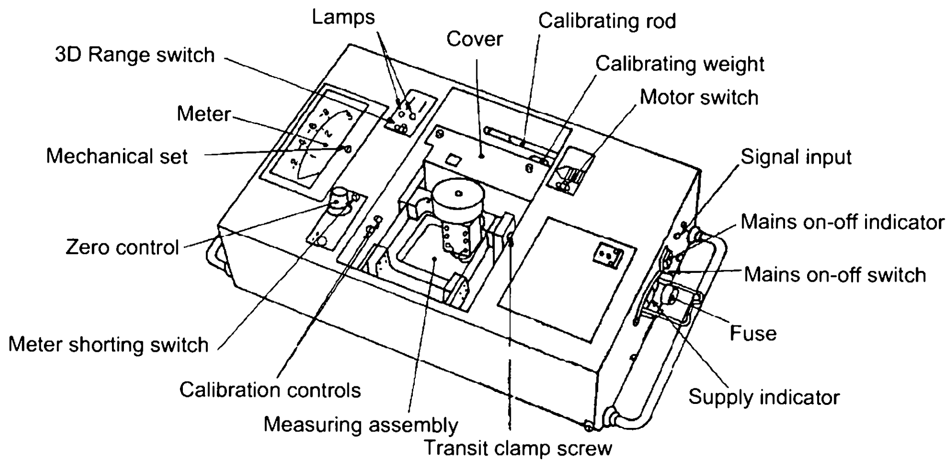

Figure 1. General view of the TORTUS system.

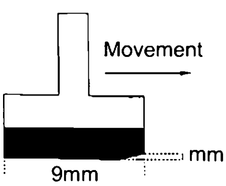

Figure 2. Shape of the rubber slider.

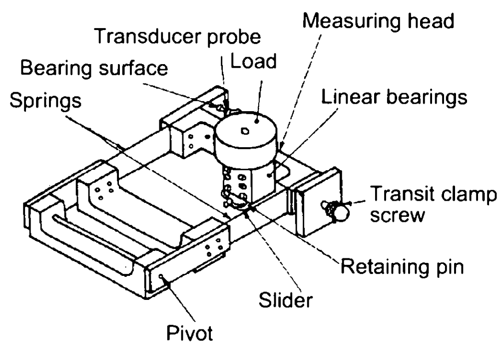

Figure 3. Tortus measurement system: force transducer.

The signal produced by the transducer is amplified and transmitted to an analogue galvanometer that indicates the coefficient of friction. The system can operate on two scales: scale 0~1, which enables readings from zero to 1; and scale 0~3, for readings from zero to 3.

The TORTUS system has an analogue signal output for a chart recorder or for an A/D signal acquisition card, which by means of a suitable algorithm enables performing automatic measurements. TORTUS system automation, via the computer-integrated A/D signal acquisition card provides faster data acquisition and analysis of each test surface.

ADJUSTMENT PROCEDURE

In accordance with manufacturer's instructions, before starting the measurement procedure, two settings need to be made. With regard to the first setting adjustment, the pointer shall coincide with the zero shown on the analogue dial and the other procedure refers to system gain. It is vital for the pointer to coincide with the bottom of the scale, which corresponds to the value 1 (one) of the coefficient of friction. This procedure is carried out with the help of a calibration rod, calibrating with a standard weight of 200 g, provided as apparatus accessories.

The assembly of these accessories simulates the horizontal force produced by a vertical load of 2.0 N on the force measurement assembly, corresponding to a coefficient of friction 1 (one), once the two (horizontal and vertical) loads have the same value. After performing this arrangement with an auxiliary potentiometer, the pointer shall coincide with the value 1 (one) in the two ranges (0~1 and 0~3).

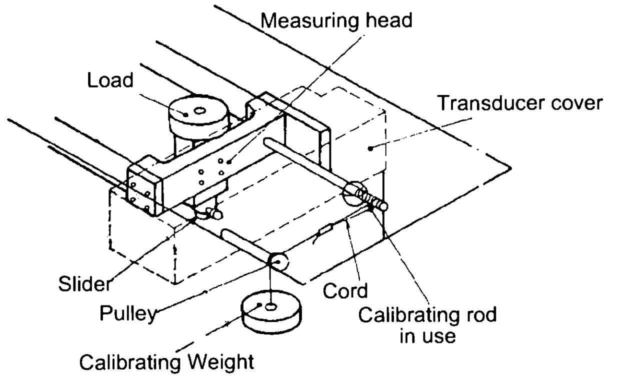

Figure 4. Adjustment of Tortus system gain.

BREAKDOWN INTO MODULES

The analysed Tortus system has an integrated computer, which by means of a signal acquisition card (A/D) obtains and processes the electrical signal associated with the force of dynamic friction. This has been termed Module I for the analysis of the Tortus analogue force measurement system. The experiments for acquiring the results of the calibration were conducted according to the adjustment procedure, using standard weights of 60g, 100g and 160g for the range 0~1; and 120g, 300g and 480g for the range 0~3, thus obtaining the readouts (n=6) on the mivoltimeter. The data were processed, calculating the correction and expanded uncertainty for each applied mass, according to the ISO Guide to the Expression of Uncertainty in Measurement.

Standard signals were input into Module II, corresponding to the computer (signal acquisition card and data processing software), by a millivolt generator. The computer screen reading (n=3) was thus obtained, calculating its correction and expanded uncertainty. The results then allowed estimating the correction curve and uncertainty of the integrated system (Module I and II).

MEASUREMENT PROCEDURE

To start the surface measurements, the apparatus needs to be suspended and the rubber slider carefully cleaned, sanding with 400 grain to remove impregnated contamination without deforming the rubber surface. The ceramic test surfaces shall then be cleaned with commercial ethyl alcohol to remove any grease, where the apparatus shall travel at least 150mm, and the result found on the computer will correspond to the average value found over this path.

The study tested some commercial ceramic floor tiles using the same procedure, comparing wet and dry conditions. In the wet test, a surface-active solution was used on the surfaces that were similarly tested.

CALIBRATION STANDARD

Unfortunately for the calibration of the system as a whole, there is no standard reference body. A laminated, tempered, smooth glass plate was used as a reference for the evaluations and analyses of the coefficient of friction. The plate was 400mm wide, 1500mm long and 6mm thick, with a dry coefficient of friction of 0.85±0.10. This periodically adapted reference was used to assess the slider enumerators and record their behaviour.

3. METROLOGICAL RELIABILITY

Classically, a metrological characterisation of the Tortus measurement system should involve complete calibration under measurement conditions. Standard surfaces with a uniform, perfectly defined coefficient of friction would be measured several times, comparing the results with reference values. This would yield the metrological characteristics of the system. However, it is not easy to obtain such reference surfaces. There are furthermore many other variables, which include: system preparation, slider surface, measurement direction and operator skill, which can introduce sources of expressive uncertainty.

The uncertainty analysis is not limited to the partial calibration of the two main modules of the Tortus system, but includes various other operating and constructive features, linked to the coefficient of friction measurement process with the Tortus system.

UNCERTAINTY SOURCES

The main uncertainty sources considered in this study are set out in the following diagram.

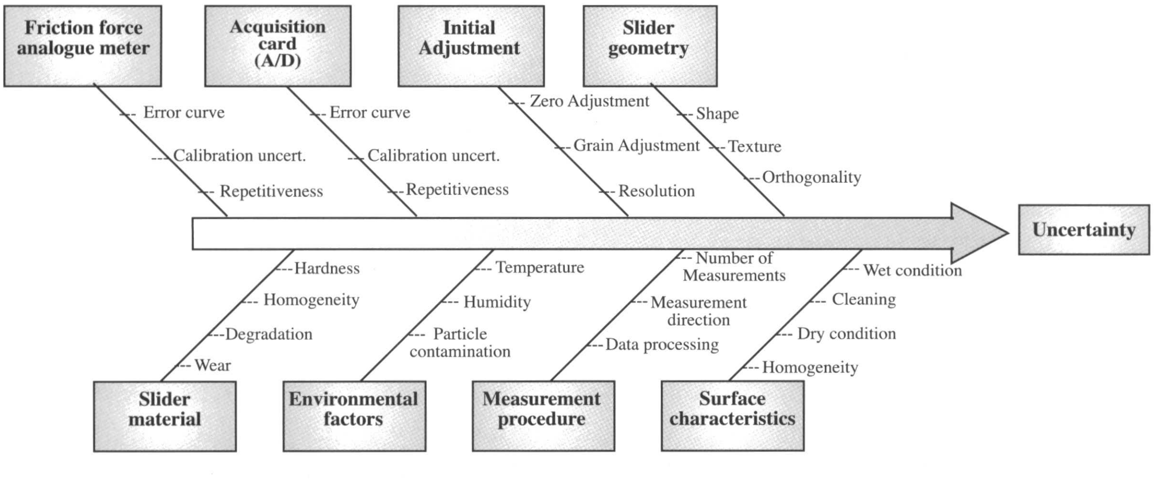

Figure 5. Diagram of the uncertainty sources considered in the uncertainty evaluation of the Tortus system.

The sources are organised in eight groups:

a) If the analogical friction force meter, though calibrated separately, does not have a properly compensated error curve, the calibration uncertainty and repetitiveness of this module will introduce uncertainties for the measurement process.

b) Signal acquisition system: this module also went through a calibration process, but for the same reason, with an improperly compensated error curve, the calibration uncertainty and repetitiveness of the module will introduce uncertainties for the measurement process.

c) Initial adjustments: zero and gain adjustments by the operator before Tortus operation and the inherent repetitiveness contribute to uncertainty.

d) Slider material: the type of slider rubber, its properties (hardness, homogeneity), ageing and wear.

e) Surface characteristics: surface quality and cleanness; homogeneity of its properties in different positions and direction. Consider also tile variations across a production lot and uniformity of the water spread over the test surface.

f) Slider geometry: the geometrical shape of the measured slider/surface contact surface, its texture (influence of wear and way of sanding), orthogonality with regard to the measured surface.

g) Measurement procedure: the number of measurements performed, directions and positions selected on the ceramic floor tile and data processing algorithm.

h) Environmental factors: temperature, humidity and environmental particle contamination where the measurements are run.

The influence of each uncertainty source is quantified and evaluated below.

4. RESULTS

The uncertainty analyses were conducted according to the ISO standard Guide to the Expression of Uncertainty in Measurement. Each uncertainty source was assessed by statistical procedures, normally by standard deviation or by non-statistical procedures, based on analytical or theoretical observations or pre-existing information. The ISO Guide terms statistical procedures "type A" and non-statistical ones "type B". These designations were also used for the uncertainty sources. In both cases, the uncertainty attributed to each was quantified by the standard deviation, i.e., the uncertainty value corresponds to a standard deviation.

ESTIMATION OF UNCERTAINTY SOURCES

A) ANALOGICAL FRICTION FORCE METER

As mentioned, the procedure adopted for calibrating the analogical system for measuring the friction force (Module I) was the black box, which basically consisted of observing the behaviour and response of the system when subjected to known and controlled input values.

The calibration yielded an error curve for the module, considering the following uncertainty sources: weights used (type B); digital multimeter indicator resolution (type B); zero adjustment (type B); of gain (type B) and repetitiveness of the indications (type A). The partial calibration of this module yielded the error curve for the calibrated range and also for the expanded uncertainty. The findings are set out in the corresponding table and figure.

Measurement range 0 to 1

Standard mass [g]	Coef. of friction VVC	Average readings	Correction	Expan. Uncert. ($U_{95\%}$)
60	0.3	0.3196	-0.0196	0.0118
100	0.5	0.5109	-0.0109	0.0104
160	0.8	0.8054	-0.0054	0.0072

Measurement range 0 to 3

Standard mass [g]	Coef. of friction VVC	Average readings	Correction	Expan. Uncert. ($U_{95\%}$)
120	0.6	0.6434	-0.0434	0.0352
300	1.5	1.5421	-0.0421	0.0351
480	2.4	2.4232	-0.0232	0.0348

Table 1. *Results of the expanded uncertainty calculation for the analogical force measurement system.*

Data analysis for the measurement range 0-1 shows that the maximum correction is 0.0196 and respective expanded uncertainty is 0.0118. The maximum error at a 95% confidence level can be estimated as the sum of the correction and estimated uncertainty in the module, i.e. 0.0196+0.0118=0.0314. Thus, maximum error would be plotted as a rectangular distribution, centred around zero, with bounds at ± 0,0314, yielding an equivalent standard uncertainty of $0.0314/\sqrt{3} = 0.0181$. Similarly, for the measurement range 0-3, the equivalent standard uncertainty, non-corrected for systematic effects, is $(0.0434 + 0.0352)/\sqrt{3} = 0.0454$.

B) SIGNAL ACQUISITION SYSTEM

To calibrate the signal acquisition system, reference stresses were generated and applied to the card input. The screen readings were compared with the reference values. In this case the uncertainty sources considered were: reference stress (type B); reading resolution (type B); data repetitiveness (type A).

The partial calibration was also analysed here, finding the error curve for the calibrated measurement ranges and their respective expanded uncertainty ($U_{95\%}$).

The results obtained from the calibration of the card show a significant systematic error, which reaches maximum values of 0.053 for the range 0~1, and 0,16 for 0~3. The response data are linear through the measurements, in contrast to the force meter, where a greater random error and a non-linear curve are found. The combination of these modules (I and II) give an uncertainty balance for the integrated system, with a greater influence of systematic error in Module II, as shown in the corresponding table and figure. The combination of the results and respective expanded uncertainties correspond to a combined maximum error of the force system/acquisition of (0.044+0.035)=0.079 for the range 0 to 1.5 coefficient of friction.

Measurement range	0~1			0~3	
Coef. friction conv.	Correction	$U_{95\%}$	Coef. friction conv.	Correction	$U_{95\%}$
0.10	-0.00062	0.0014	0.30	-0.00186	0.0041
0.20	0.00522	0.0011	0.60	0.01567	0.0034
0.30	0.01205	0.0005	0.90	0.03614	0.0016
0.40	0.01873	0.0008	1.20	0.05619	0.0023
0.50	0.02410	0.0007	1.50	0.07231	0.0020
0.60	0.02965	0.0004	1.80	0.08894	0.0020
0.70	0.03525	0.0001	2.10	0.10576	0.0001
0.80	0.04140	0.0004	2.40	0.12421	0.0015
0.90	0.04747	0.0008	2.70	0.14242	0.0024
1.00	0.05345	0.0003	3.00	0.16035	0.0006

Table 2. Results of the correction and expanded uncertainty per level.

Measurement range 0~1			Measurement range 0~3		
Coef. friction Conv.	Correction	$U_{95\%}$	Coef. friction Conv.	Correction	$U_{95\%}$
0.10	-0.024	-	0.30	-	-
0.20	-0.015	-	0.60	-0.029	0.035
0.30	-0.007	0.012	0.90	-0.005	-
0.40	0.002	-	1.20	0.020	-
0.50	0.011	0.010	1.50	0.044	0.035
0.60	0.020	-	1.80	0.068	-
0.70	0.028	-	2.10	0.092	-
0.80	0.037	0.007	2.40	0.116	0.035
0.90	0.046	-	2.70	-	-
1.00	0.055	-	3.00	-	-

Table 3. Results of the combination for Tortus A.

Resulting calibration curve
TORTUS A

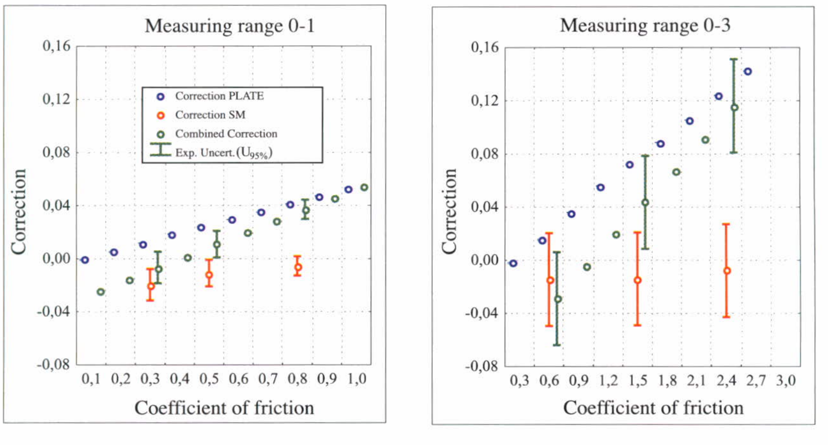

Figure 6. Curve resulting from the calibration of Tortus A.

C) INITIAL ADJUSTMENTS

The effect of the initial adjustments on the measurements were estimated from the observations of the uncertainty limits for the following factors: zero adjustment (type B); gain adjustment (type B); resolution of the analogical reading (type B). The adjustment uncertainties were estimated for each range, the equivalent to 1/6 of the smaller division, so that 0.02/6 = 0.0033 for 0~1 and 0.10/6=0.0167 for 0~3. Thus for the analogical reading resolution uncertainty a gross value was considered, equivalent to 1/4 of the smaller division, i.e., 0.005 and 0.025 for ranges 0-1 and 0-3, respectively.

D) LONG-TERM STABILITY

Series of coefficient of friction measurements were run under the same conditions and with the same sliders on a plate of tempered glass, used as a reference, where they were collected for slider assessment over a period of several months. Each slider, referenced by a different letter, should exhibit similar characteristics. The following table sets out the results with the test dates, while the figure plots the dynamic coefficient of friction versus test date.

The values are the average of ten tests run on the same day with each slider. The data indicate a great variation in values with time, reaching a standard deviation of the order of 0.47 for the coefficient of friction. These data present excessively high variations. The factors responsible for such a great variation were therefore investigated, quantifying the influence of each. The analyses follow.

Average

	I	J	K	L	M	N
Performed on 15/04/97	1.016	0.799	0.873	0.984	0.973	1.030
Performed on 31/07/97	1.109	0.895	0.821	1.299	1.164	1.258
Performed on 17/10/97	1.298	1.254	1.050	0.828	1.065	1.065
Performed on 03/03/98	1.249	0.976	0.945	1.088	1.238	1.498
Performed on 19/05/98	1.096	0.967	1.018	1.176	1.133	1.202
Average	1,154	0.978	0.941	1.075	1.115	1.211
STD dev.	0,104	0.152	0.086	0.161	0.090	0.167
Diff=max.-min.	0,282	0.455	0.229	0.471	0.265	0.468

Deviation

	I	J	K	L	M	N
Performed on 15/04/97	0.114	0.038	0.056	0.068	0.029	0.045
Performed on 31/07/97	0.033	0.031	0.023	0.076	0.074	0.088
Performed on 17/10/97	0.088	0.049	0.060	0.028	0.106	0.030
Performed on 03/03/98	0.224	0.087	0.116	0.177	0.123	0.125
Performed on 19/05/98	0.069	0.047	0.047	0.058	0.084	0.063

Table 4. *Results of the sliders on the reference glass surface.*

E) CHARACTERISTICS OF THE REFERENCE SURFACE

As observed, the coefficient of friction did not have the same value, so that tests were run changing the position on the reference surface under dry and wet conditions. Three positions were thus used on the glass surface, with one class of slider (type K). The following table and figure present the results.

Evaluation of types of sliders with time

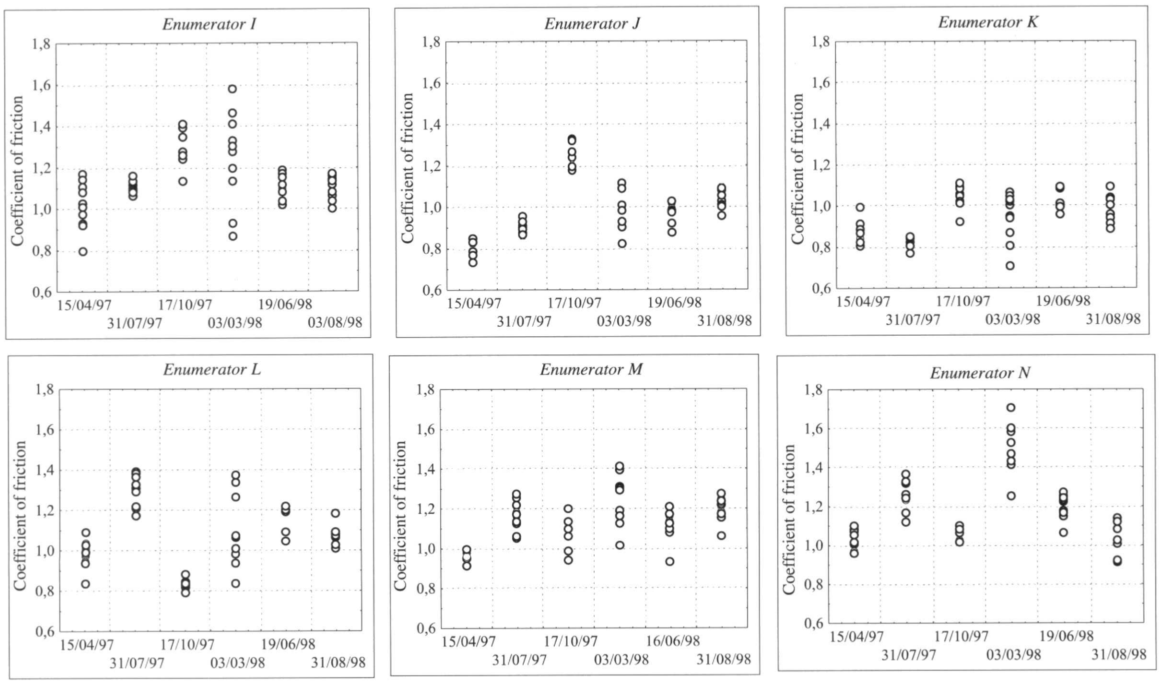

Figure 7. Variation of results in terms of slider type and time.

	Dry		Wet	
Position	Average	Deviation	Average	Deviation
K_I	0.8423	0.1192	0.3252	0.019
$K_{II.}$	0.9082	0.0503	0.3192	0.028
K_{III}	1.0056	0.1007	0.3048	0.009

Table 5. Results of the tests evaluating the position on the glass under wet and dry conditions.

Behaviour in different positions
Reference surface (glass)

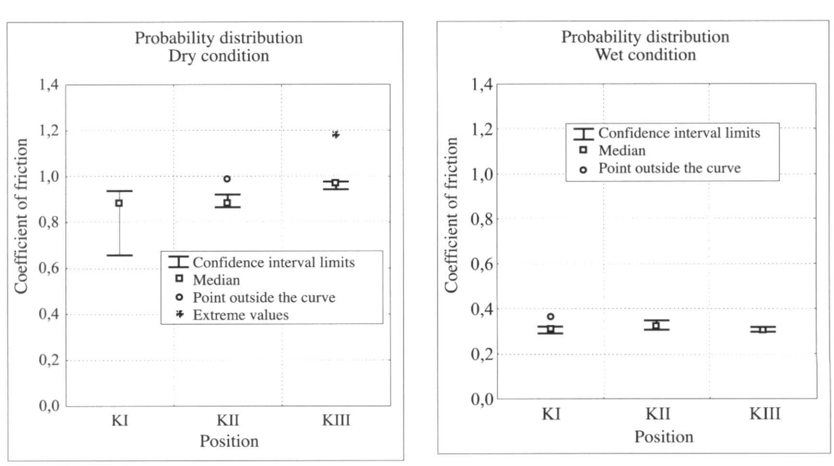

Figure 8. Variation of the coefficient of friction on the reference plate under wet and dry conditions.

These results under dry conditions indicate that the tempered glass surface cannot be adopted as a reference surface as the value found for the coefficient of friction varies significantly, both on average and in the deviation..

The wet condition is striking for two reasons: the considerable drop in the coefficient of friction and the reduction in the deviation that becomes about 5.5 times smaller. Owing to the extent of the variations, the dry and wet test results needed to be processed separately. However, for the analysis of the system, the dry condition was used, setting a single position and direction to minimise the influence of variations over the tempered glass surface.

F) SLIDER GEOMETRY (GD); RUBBER SURFACE TEXTURE (TEX) AND TYPE OF MATERIAL (MD)

The cleaning procedure of the rubber contact area can introduce errors if not correctly performed, together with wear. To estimate the uncertainty of these factors, aspects were considered such as: shape of the slider before and after wear (type A); textural characteristics as a result of surface sanding (type A); orthogonality of slider/measured surface.

The influences were analysed of slider contact surface texture (type K) in which parallel grooves were made by a file (K_{rpll}), as well as grooves perpendicular (K_{rperp}) to the direction of travel. Shape and material were analysed with sliders of the E type (imported, 4S); K and J. All the tests were conducted in the position on the glass surface.

	Before		After	
Type of slider	Average	S	Average	S
E	1.0461	0.0817	0.8009	0.0232
K	0.8297	0.0932	0.8788	0.0584
J	0.8742	0.1130	0.7739	0.1012
K_{rpll}	-	-	0.7209	0.0710
K_{rperp}	-	-	0.9082	0.0503

Table 6. *Results obtained on testing with different sliders.*

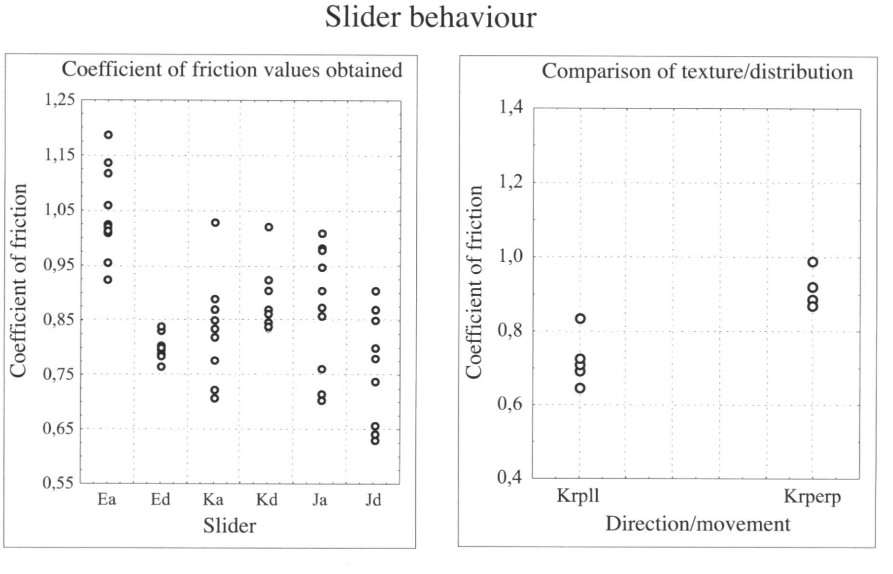

Figure 9. *Slider behaviour: shape, planarity and texture.*

G) MEASUREMENT PROCEDURE

To suitably characterise the metrological reliability of a measurement process, the data collection and processing strategy also needs to be assessed. These involved aspects such as: number of measurements performed, statistical procedures for measurement estimation and direction adopted on the measuring surface in different positions for measuring the coefficient of friction.

The evaluated analyses up to this point were the uncertainty sources stemming from the Tortus system and its operation. The variations in the measured floor surface also need to be taken into acount, which may not be uniform.

H) ENVIRONMENTAL FACTORS.

In the context of this study, it was not possible to perform isolated experiments for each factor. The results were obtained in the laboratory with a negligible contamination from a surface-active solution, used to obtain the data under the wet condition on the glass surface and for the commercial floor tiles.

INTEGRATED COMBINED UNCERTAINTY ESTIMATION

The data found correspond to the behaviour of measurement system characteristics and their uncertainty sources, from the force measurement system and the signal processing system to the external influences such as system preparation by the operator. On grouping these uncertainty sources, it was possible to calculate the estimated expanded uncertainty for the same position on the glass with a value of 0.317, and confidence interval of 95%.

Type A sources	S(q)	n
I_{GD}	0.0825	60
I_{MD}	0.0526	30
$I_{TEX.}$	0.0971	10

Table 7. *Results of the standard uncertainties for type A uncertainty sources.*

Enumerator K; range 0~3; dry condition; same position		MI = 0.879				
Uncertainty components		Random				
size	description	gross val.	prob. distr	divisor	uncertainty	ν_i
u_a	Repetitiveness (Type A)	0.0248	normal	1	0.0248	54
$E_{max.}$	Max. calibration error	0.0790	rectangular	$\sqrt{3}$	0.0456	inf.
$E_{reg.}$	Adjustment error	0.0344	rectangular	$\sqrt{3}$	0.0199	inf.
I_{GD}	Slider shape	0.0825	normal	1	0.0825	20.6
I_{MD}	Slider material	0.0526	normal	1	0.0526	14.5
$I_{TEX.}$	Slider texture	0.0971	normal	1	0.0971	5.1
$\mathbf{C_c}$	Combined correction					
$\boldsymbol{u_c}$	Combined uncert.		normal		0.149	24.196
$\mathbf{U_{95\%}}$	Expanded uncert.		2.13		0.317	

Table 8. *Typical uncertainty balance of the Tortus system under dry conditions (tempered glass).*

For the estimation of the results under the wet condition, a reduction was found in the deviations of about 5.5 times the value, in the sources used under dry conditions. Based on the measurements performed before on glass, the reduction assumption was considered in other estimated sources (shape, planarity and material) with an expanded uncertainty of 0.113 and confidence interval of 95%.

Enumerator K; range 0~3; wet condition; same position		MI = 0.316				
Uncertainty components		Random				
size	description	gross val.	prob. distr	divisor	uncertainty	ν_t
u_a	Repetitiveness (Type A)	0.0081	normal	1	0.0081	54
$E_{max.}$	Max. calibration error	0.0790	rectangular	$\sqrt{3}$	0.0456	inf.
$E_{reg.}$	Adjustment error	0.0344	rectangular	$\sqrt{3}$	0.0199	inf.
I_{GD}	Slider shape	0.0148	normal	1	0.0148	20.634
I_{MD}	Slider material	0.0094	normal	1	0.0094	14.549
$I_{TEX.}$	Slider texture	0.0174	normal	1	0.0174	5.112
C_c	Combined correction					
u_c	Combined uncert.		normal		0.056	477.8
$U_{95\%}$	Expanded uncert.		2.01		0.113	

Table 9. *Typical uncertainty balance of the Tortus measurement system under wet conditions and smooth surfaces (tempered glass).*

For the results to be carried over to the determination of the coefficient of friction, certain considerations needed to be adopted. Experience shows that Tortus repetitiveness largely depends on test surface characteristics. The estimated value for the glass should not be used, so that the "repetitiveness" uncertainty source was removed from the uncertainty balance. This parameter was re-calculated without repetitiveness, obtaining a combined uncertainty of 0.147. For the wet condition, the estimated uncertainty is 0.056, presenting a reduction of 38% of the combined dry uncertainty..

Enumerator K; range 0~3; dry condition						
Uncertainty components		Random				
size	description	gross val.	prob. distr	divisor	uncertainty	ν_t
$E_{max.}$	Max. calibration error	0.0790	rectangular	$\sqrt{3}$	0.0456	inf.
$E_{reg.}$	Adjustment error	0.0344	rectangular	$\sqrt{3}$	0.0199	inf.
I_{GD}	Slider shape	0.0825	normal	1	0.0825	20.634
I_{MD}	Slider material	0.0526	normal	1	0.0526	14.549
$I_{TEX.}$	Slider texture	0.0971	normal	1	0.0971	5.1
C_c	Combined correction					
u_c	Combined uncert.		normal		0.147	22.874
$U_{95\%}$	Expanded uncert.		2.13		0.312	

Table 10. *Uncertainty balance of the measurement under dry conditions.*

On considering these values as the measurement system uncertainty, the value of the glass coefficient of friction in different positions, for the wet and dry conditions, can be observed in the table and graph. The result for the combined uncertainty of the glass surface is 0.192 under dry conditions and 0.060 for wet conditions, with an expanded uncertainty of 0.388 and 0.119 respectively, at a confidence interval of 95%.

Dry condition						
System	Tortus A slider K	0.312	normal	2	0.156	inf.
Glass	Position	0.112	normal	1	0.112	14
u_c	Combined uncert.				0.192	121.709
$U_{95\%}$	Expanded uncert.		2.02		0.388	
Wet condition						
System	Tortus A slider K	0.112	normal	2	0.056	inf.
Glass	Position	0.021	normal	1	0.021	14
u_c	Combined uncert.				0.060	938.953
$U_{95\%}$	Expanded uncert.		2		0.119	

Table 11. *Results of the glass measurement.*

The uncertainty sources; geometry, material and texture of the slider for the calculation of measurement system uncertainty under the wet condition were estimated at a reduction of 62%, the sources also being affected by the contamination with favoured a reduction in experimental deviation. The figures show the combined uncertainty of the measurement system with the result of the glass surface measurement.

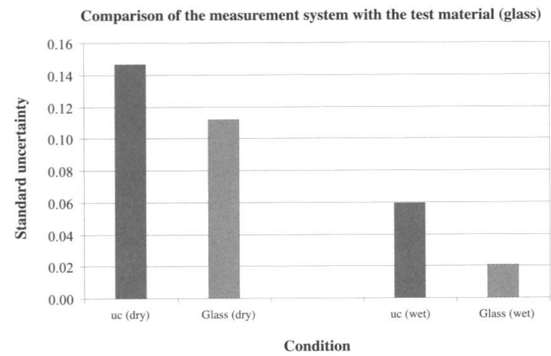

Figure 10. *Results of the uncertainty of the measurement system and variable to be measured (glass).*

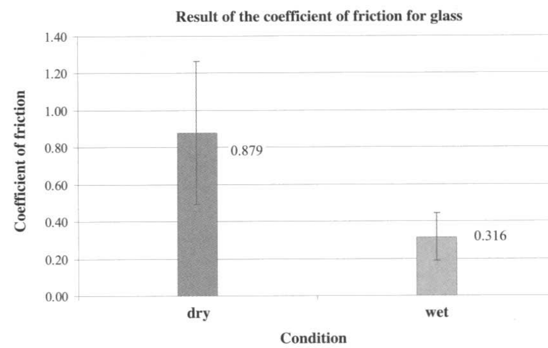

Figure 11. *Results of surface measurement (glass).*

On evaluating the estimations of the uncertainty sources in the measurement process under dry conditions and a smooth surface, a comparative graph can be constructed as the figure shows. It can be observed that under this condition, the greatest effects correspond to the type of selected material and slider preparation, yielding 86% on the combined uncertainty and an expanded uncertainty of 0.312, certainly high for this measurement process.

Under the wet condition, the greatest influence corresponds to the calibration of the friction force measurement system, with about 68% for the influence of the combined uncertainty of 0.05 equivalent to 0.11 expanded uncertainty. The result shows contamination to be an important factor in the measurement of the friction coefficient compared with the dry condition.

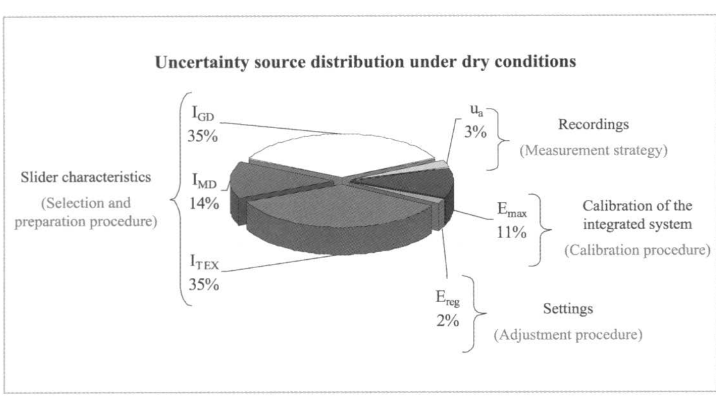

Figure 12. *Uncertainty source proportions in the measurement process with the Tortus system under dry conditions and a smooth surface.*

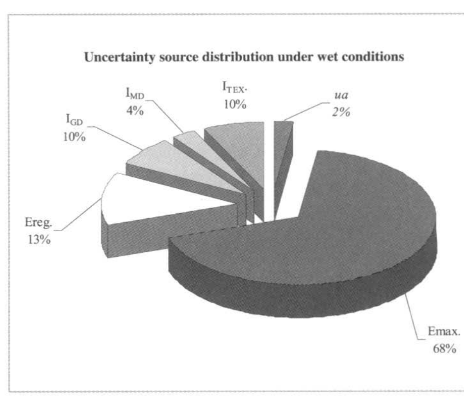

Figure 13. *Distribution of the uncertainty sources of the measurement process with the Tortus system under wet conditions and a smooth surface.*

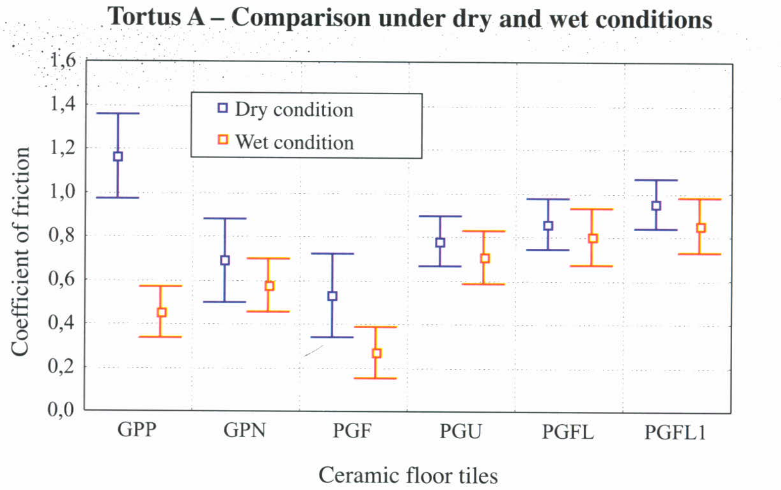

Figure 14. Results of the coefficient of friction on ceramic floor tiles.

VERIFICATION MEASUREMENTS ON COMMERCIAL CERAMIC FLOOR TILES.

Variations in floor tile surface properties occur during manufacture. These properties are related to finished product type and surface characteristics, whether obtained by incorporating particles or by modifications of the profile to produce greater slip resistance.

A series of measurements was performed on two ceramic floor tile surfaces, which exhibit the typical variation ranges of the properties and their estimated respective uncertainties for the TORTUS system, quantifying the coefficient of friction. Thus repetitive measurements were made in several directions on the same surface with the Tortus system. The results are shown below.

Sample codes	Commercial type
GPP	Polished Porcelain tile
GPN	Natural porcelain tile
PGF	Floor tile with melted granular
PGU	Floor tile with uniform granular
PGFL	Floor tile with sanding-type granular
PGFL1	Floor tile with type 1 melted granular

***Table 12.** Selected commercial floor tiles for the tests.*

	Tortus A		
	Dry	Wet	Δ(%)
GPP	1.1649	0.2684	76.96
GPN	0.6887	0.5753	16.47
PGF	0.5300	0.2684	49.36
PGU	0.7803	0.7055	9.90
PGFL	0.8595	0.8001	6.91
PGFL1	0.9523	0.8522	10.51

***Table 13.** Comparative results of wet and dry averages.*

The results of the measurements performed on ceramic floor tiles show that the granular surfaces present similar results under wet and dry conditions. However, the polished surfaces do not have similar results. Moreover they exhibit high uncertainties of 0.12 for wet conditions and 0.5 for dry conditions. These results indicate that care needs to be taken with the Tortus measurement system, on objectifying the coefficients of friction on ceramic floor tiles.

CONCLUSIONS

As a result of this study, the importance was verified of correctly characterising slip on ceramic floor tiles. The values found with regard to slip from a safety viewpoint help to avoid injury caused by falls particularly in public and industrial environments.

A trend was found in the standards to only specify the average value to characterise the coefficient of friction, using a measurement system that requires care in its measurement process, while the different systems involved present systematic and random errors. It is therefore hardly enough to calculate the average readings. If certain measures of care are not taken, the uncertainties of the Tortus system can reach 40% of the average value.

A classic evaluation could not be performed of the Tortus system, as it does not have a reference surface, with a defined and known coefficient of friction. However, the following conclusions were drawn as a result of various separate tests and detailed analysis of the results:

- The most critical element of the analysed systems was the signal acquisition card (A/D), which can be detected by calibration and corrected.

- The rubber slider is the most critical element. Factors such as type of slider material, planarity and contact surface texture also strongly affect the coefficient of friction measurement results.

- Under wet conditions, contamination has a pronounced effect on the results of the uncertainty estimation of the measurement system, producing a drop of up to 60%.

- Under wet conditions, depending on the other uncertainty sources, the greatest source is the error associated with the friction force meter.

It was also established that with some care, the metrological performance of the Tortus system could be optimised to reduce its uncertainty. The following is therefore recommended:

⇒ Always use the same type of standard slider (4S) and in the case of an equivalent material, the choice should not only be on the basis of the nominal characteristics of the rubber but also on the response of the actual Tortus system for the type of floor material analysed.

⇒ Standardise slider cleaning procedures by a device capable of maintaining the orthogonality of the slider with the sanding surface, performing random movements so as not to produce grooves with preferential directions.

⇒ Periodically calibrate the force system and correct its systematic errors by fitting or correction tables.

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