OPTIMISED COMBINATIONS OF CERAMIC FLOORING AND FOOTWEAR FOR WORK ENVIRONMENTS

G. SILVA[1];A. BELTRÁN[1]; A. MUÑOZ[1]; I. ESCRIG[1]; C. LLOBELL[2] ; M. SANCHÍS[2]; G. LILLO[2]

[1] **Instituto de Tecnología Cerámica (ITC). Asociación de Investigación de las Industrias Cerámicas (AICE), Universitat Jaume I. Castellón. Spain.**

[2] **Instituto Tecnológico del Calzado y Conexas (INESCOP). Elda. Spain.**

1. ABSTRACT

Slipping is a complex phenomenon in which a high number of variables intervene that condition the magnitude of the available friction (such as type of activity and gait, speed, temperature, type of contaminant and lubrication, type of flooring, topography and surface roughness, type of footwear, sole design and materials of which it is made, etc.). Despite great efforts made in many countries to obtain a better understanding of friction phenomena, the studies conducted have been largely unsuccessful due to the absence of a holistic approach to the problem of slipping.

This paper has been developed from an integrated approach, simultaneously considering the three basic elements that contribute to friction (flooring, contaminant and footwear) and the use conditions and specific requirements (e.g. asepsis, chemical aggressiveness, etc.) which characterise the various studied occupational environments (industrial, food and healthcare). The possible effect on non-slip performance of changes arising from actual use (e.g. cleaning and maintenance) were also analysed in order to maximize the useful life of the combinations proposed for each environment. The results obtained allow definition of the selection criteria for optimal combinations of flooring and footwear for each specific use environment.

2. INTRODUCTION

The European Agency for Safety and Health at Work (EU-OSHA) confirms that falls on a single level are the main cause of accidents in all sectors. It is estimated that this type of accident accounts for 40% of all falls, mainly caused by slips (resulting from poor footwear grip to the floor) and tripping (usually from excessive footwear grip to the floor). Nationally, statistics in 2014 [1] showed that people falling on a single level accounted for 16.8% of the total number of workplace accidents with sick leave, 0.8 % of these accidents being serious.

Despite evidence of the existing risk, occupational risk prevention regulations applicable to floors simply provide a general warning that "The floors of workplaces must have no dangerous bumps, holes or slopes and must be fixed, stable and not slippery", without establishing an assessment method or a minimum reference value. In the footwear context, although there are no specific requirements for different workplace environments, at least there is a harmonised standard for assessing slip resistance [2], based on the fact that footwear can be classified according to its coefficient of friction (CoF) into one of the following categories:

Designation	Contaminant	Surface	Heel/flat CoF
SRA	Water+detergent	Eurotile (porcelain UGL natural)	0.28/0.32
SRB	Glycerine	Polished steel	0.13/0.18
SRC	Meets both SRA and SRB conditions		

Table 1. *Slip classes in professional footwear.*

For the rest of non-occupational footwear, no requirements are established, but their respective regulations recommend a minimum coefficient of friction of 0.28 for heel and 0.30 for flat, when the test is with "Eurotile 2" contaminated with water+detergent.

In this context, the selection of a suitable combination of flooring and footwear for each workplace is left up to the facility's user, so that a wide variety of actual situations are to be found, as a function of the priorities assigned to other specific requirements of the facility (cleanability, presence of chemicals or other contaminants, etc.). For this reason, prior to undertaking this study, an analysis of the usual conditions in healthcare, food and industry work environments was conducted, by surveys in actual workplaces and consultations with flooring and footwear manufacturers with commercial products for these uses. As can be seen in **Table 2**, there is a wide variety of possible actual situations, so it was decided to tackle the study by considering a broad spectrum of combinations.

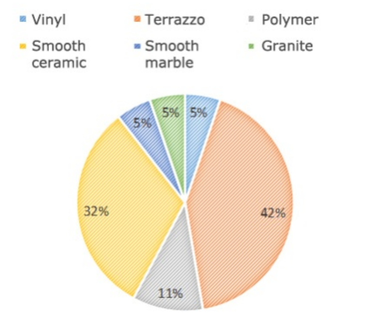
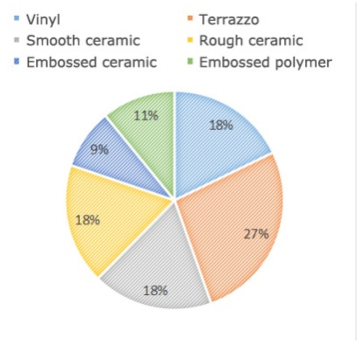
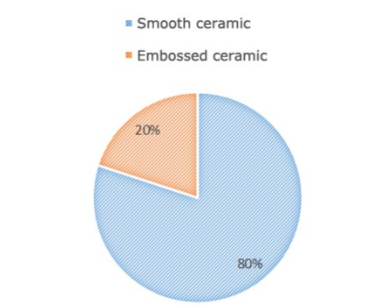
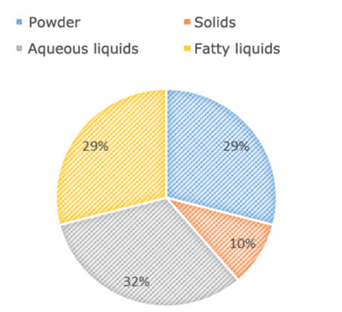
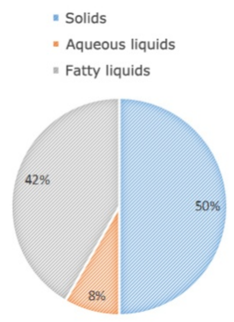
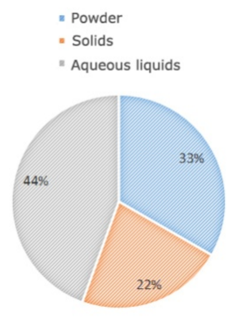
Healthcare	Food	Industry
		
Types of flooring		
		
Types of contaminants		

Table 2. *Types of flooring and contaminants according to workplace.*

3. ASSESSMENT OF SLIP RESISTANCE

To undertake the study, 3 floorings with a glossy or satin finish (healthcare environment), 3 floorings with a rough or embossed textured finish (food environment) and Eurotile 2 (test surface in ISO 13287) were selected. Five kinds of footwear for occupational use (personal protective equipment, PPE), usually employed in food-healthcare (AS) and industrial (I) environments, respectively, were also selected.

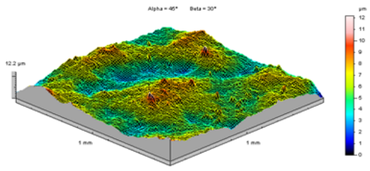
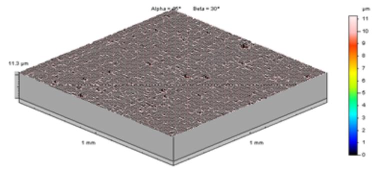
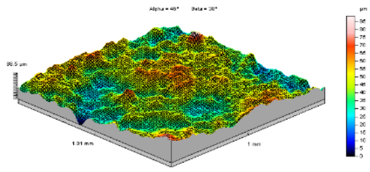
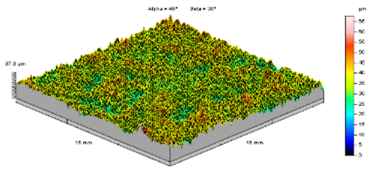
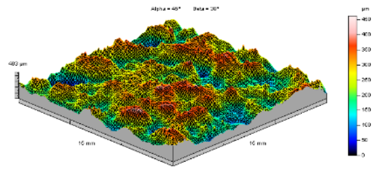
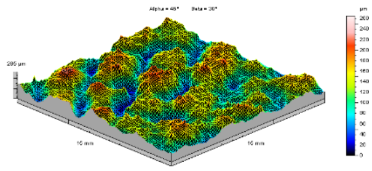
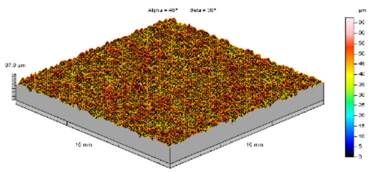
		
Glossy ceramic (10)	Smooth polymer (14)	Vinyl (25)
		
Rough ceramic (53)	Embossed ceramic (69)	Sandblasted polymer (32)
		
Eurotile 2 (29)	EVA-AS (self-certified)	PU-AS
		
PU-TPU-AS (SRA)	PU-R-I (SRA)	PU-TPU-I (SRA)

Table 3. *Selection of floorings (PTV57 value) and footwear (Class ISO 13287).*

The combinations of flooring and footwear were tested using the method described in the footwear standard (UNE-EN ISO 13287) and the ramp method (CEN/TS 16165 Annex B) respectively, replacing the reference surfaces and footwear with the selected flooring and footwear samples (Figure 1). The tests with both methods were carried out using two kinds of contaminants: water with detergent (0.5% SLS) and oil (SAE 10 W 30)/glycerine.

In addition, slip resistance was measured by means of other commonly used methods on floors, listed in Table 4, and the reference tile STD-P established in the Spanish standard project PNE 41901 EX was included as an additional sample, so that a comparative assessment could be made of the reference surfaces for footwear and flooring test methods.

Classification	Slider	Contaminant
Friction pendulum -CEN/TS 16165 Annex C	IRHD 57 and 96	Water
Dynamic COF – ANSI A326.3	SBR (Shore A 95)	Water+0.05% SLS
Ramp – DIN 51130	LeipzigV73-SP	SAE 10 W 30

Table 4 *Floor test methods.*

Figure 1 *Footwear test method and ramp test method.*

The test method for footwear consisted of determining the coefficient of friction as the ratio between the friction force (parallel to the surface) and the vertical force, while the footwear was displaced linearly on the surface at a speed of 0.3 m/s. Although the standard includes the possibility of testing in conditions of heel support, flat or thenar, in this study the tests were performed exclusively with total contact on the flooring surface (flat test). To enable comparison of the CoF values with the critical angle results obtained using the ramp method, it was assumed that the CoF could be calculated as the tangent of the angle obtained.

On performing a comparative analysis of the test results using an aqueous solution of sodium lauryl sulphate (SLS), it was observed that the values obtained with the ramp were higher than the result with the footwear test, especially in the high CoF range of values, in some cases even exceeding the scale limit (0.8) in the ramp test, equivalent to a 39° slope of the platform (Figure 2). It may be assumed that, in a hazard prevention situation, the gait adjustment capacity makes more effective use of available friction [3, 4] when testing with actual subjects, compared to mechanical testing of footwear in which the slipping speed and vertical force distribution are constant. This does not imply that the ramp test should be deemed more suitable for assessing friction with footwear, since the gait on a sloping plane will not always be representative of the conditions on horizontal flooring.

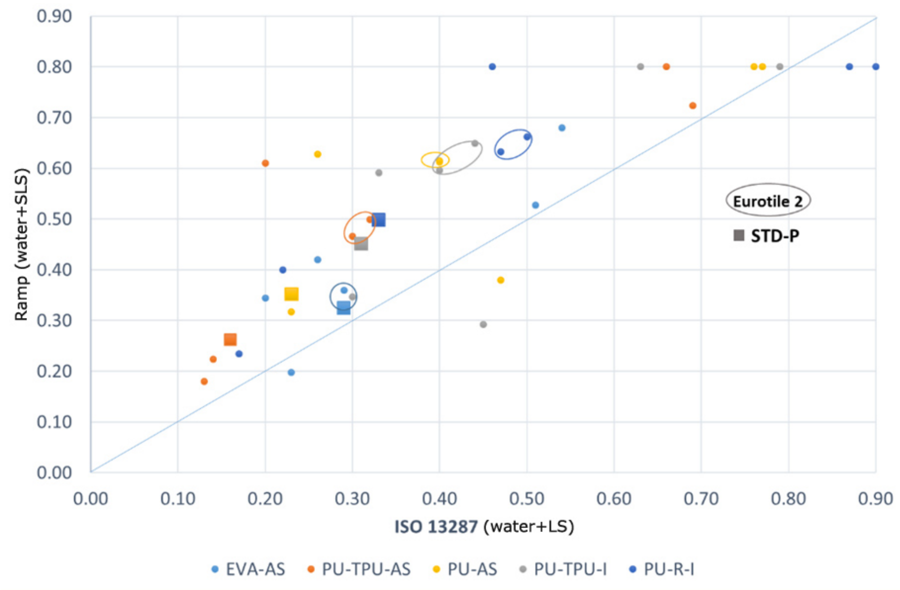


Figure 2 *Comparison of test results with water and detergent.*

In contrast, the results obtained with oil/glycerine displayed considerable correlation in the CoF<0.30 range (Figure 3), perhaps because the sudden acceleration at the moment of loss of adherence in the ramp test limited the efficiency of the ergonomic adaptation mechanisms. For higher CoF values, in the range of rough surfaces and with an embossed texture, no correlation between the methods was observed.

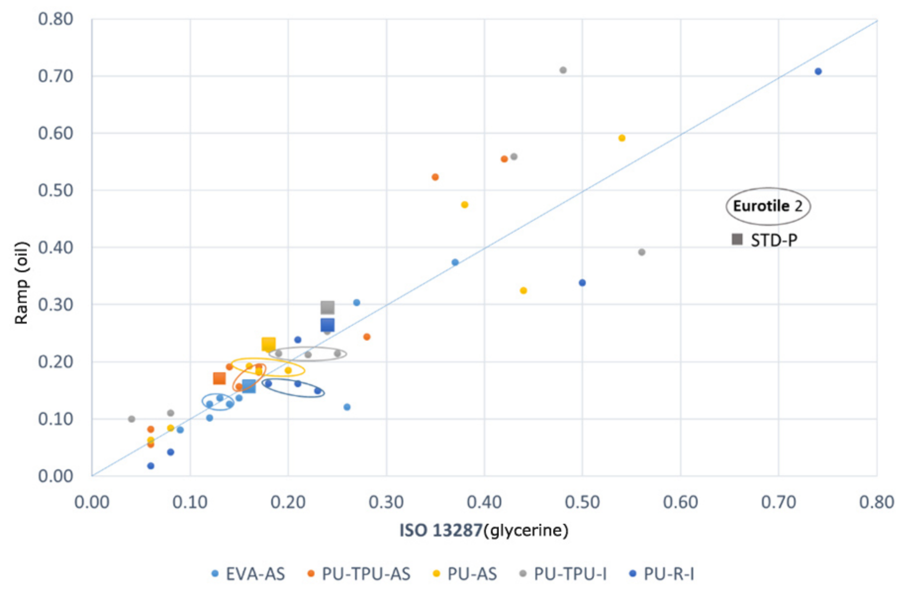


Figure 3 *Comparison of test results with oil/glycerine.*

In Figure 4, the results are analysed from the point of view of the combination of types on different floor surfaces for the tests with water contamination. The floorings are shown in ascending order of classification with regard to the friction pendulum test (red line), assuming that the CoF value could be calculated by dividing the PTV57 by 100 and the footwear with regard to the value obtained with the tribometer on Eurotile 2.

As can be seen, in the case of low roughness surfaces the appropriate selection of footwear was critical, permitting an improvement in the available friction of around 0.3 units, although it must be emphasised that, for glossy smooth surfaces, optimal footwear did not always coincide with the expected order based on the ISO 13287 test results.

Similarly, in Figure 5 the results of the test with oil are presented compared to the value obtained with the reference footwear in the DIN 51130 standard (red line). In conditions with oil contamination, only the rough surfaces or the ones with an embossed texture allowed a safe available friction level, greater than 0.30 [5], to be reached, whilst for the rest of the surface types this was not feasible despite using occupational footwear.

On comparing the results obtained with both contaminants, it was verified that it was not possible to correlate friction measurements under different contamination conditions [6]. In water contamination conditions, the surface with medium roughness (Eurotile 2) exhibited greater friction than the surface with slight embossing (STD-P), whilst with oil this situation was reversed, embossed surfaces providing higher values. It may thus be concluded that the friction mechanisms were different, depending on the surface geometry and type of contaminant present.

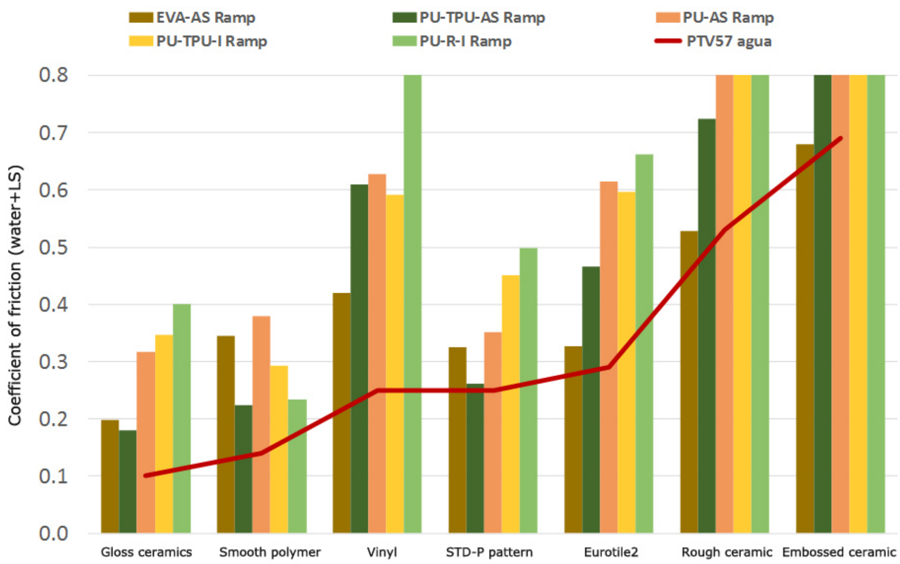


***Figure 4** Ramp tests with water/detergent solution.*

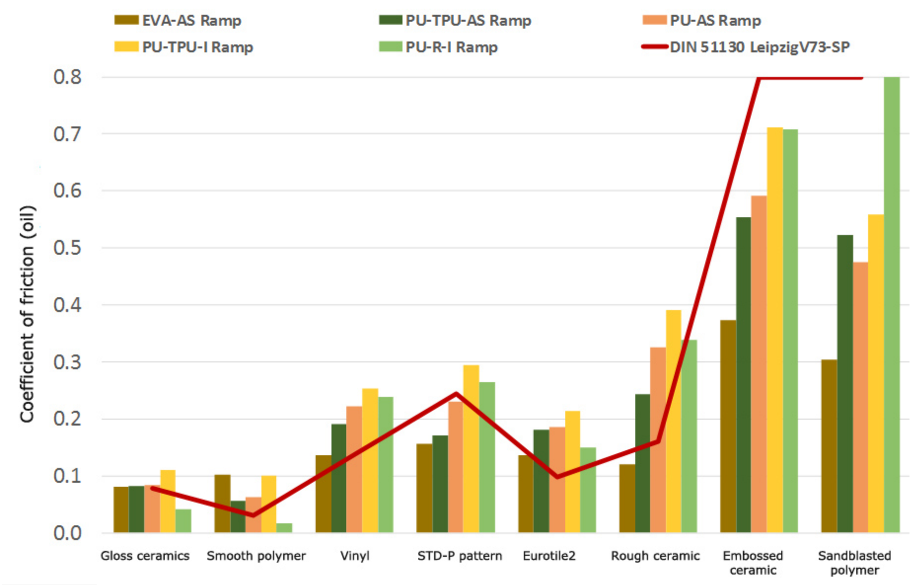


***Figure 5** Ramp tests with oil.*

4. INFLUENCE OF SOLID CONTAMINANTS

The results of the surveys conducted in actual use situations confirmed that the presence of contamination with solids was significant in the three work environments. In order to analyse their influence, a representative solid contaminant was selected for each of the environments, covering a range of particle sizes associated with the three possible friction mechanisms in the solid contaminant conditions described in the literature [7], as listed in Table 5. Due to the difficulty of achieving a reproducible contaminant distribution on the surface required for the ramp tests with footwear, it was decided to assess the impact of these contaminants using the friction pendulum method. To compare the results in clean and dry floor conditions, the tests were performed using IRHD 96 rubber, as set out in Spanish draft standard PNE 41902 EX.

Friction mechanism	Average particle size	Nature
Slipping without cohesive fracture of the solid contaminant layer	10-15 microns Healthcare environment	Talc
Slipping due to shearing of the solid contaminant layer	20-30 microns Food environment	Flour
Slipping due to rolling on solid particles	100-200 microns Industrial environment	Quartz (sand)

***Table 5** Selected solid contaminants.*

In Figure 6, the results obtained for the various contaminants are presented for a range of floorings, in ascending order in respect of their PTV96 in water contamination conditions.

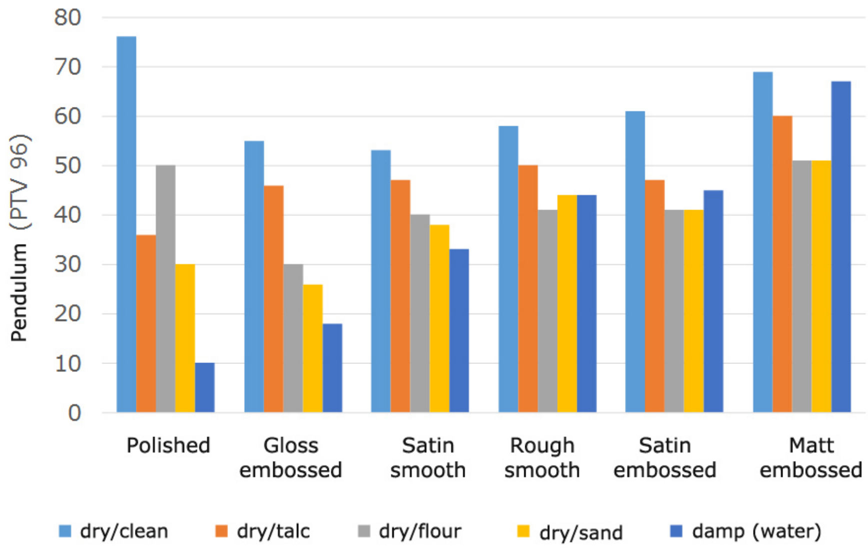


Figure 6 *Tests with solid contaminants.*

Friction in the absence of contaminants (clean and dry) was highly affected by adherence phenomena, and therefore by the effective contact surface between flooring and footwear. This explains why the polished surface presented the maximum PTV96 value, which decreased for undulating or slightly rough surfaces and finally increased again in the case of embossed surfaces, although not recovering the maximum adherence value. For this reason, the presence of both solid and liquidcontaminants affected smooth and glossy surfacesmore markedly, and their impact gradually decreased when the surface had other elements which favoured contact or anchorage, such as roughness and embossing.

Although the PTV96 values in contaminant conditions with solids were in general greater than the values required for available friction described in the literature, slip falls have been recorded in these circumstances, although less frequently than in contamination with liquids. It must be considered that variation in respect of the "clean and dry" condition is very high on glossy or low roughness surfaces, which may limit the capacity for balance recovery in the case of slipping. Conversely, rough or embossed surfaces exhibit lower sensitivity to contamination with solids.

5. INFLUENCE OF OTHER AGENTS PRESENT

In order to assess the possible change in flooring performance associated with actual use and cleaning and maintenance media, ceramic samples with different surface finishes were installed in the aisles of the self-service areas of the Universitat Jaume I dining halls (Figure 7). As it was a one-way traffic zone, delimited by handrails, the number of persons walking on the pieces being studied was quantified using optical counters placed at the exit and next to the cash registers.

Slip resistance on these surfaces was periodically assessed using the friction pendulum (PTV57) and dirt retention was measured using a portable spectrophotometer (ΔE). The progressive measurements of change in colour were done on the surfaces as they were found, without any additional cleaning other than that routinely carried out by facility staff.

Figure 7 *Assessment under real use conditions. Food environment*

As had been noted in previous studies [8], rough surfaces, both smooth and embossed, tended to show a significant reduction in slip resistance in the initial stages of exposure to real conditions of wear by pedestrian traffic (Figure 8). Conversely, low roughness surfaces kept this fairly stable, although at significantly lower values.

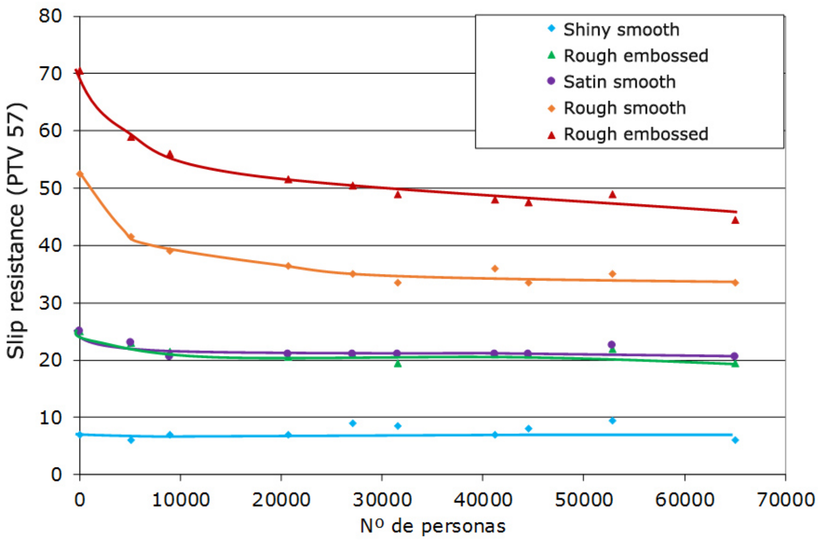


Figure 8 *Evolution of friction.*

In relation to dirt retention, all surfaces showed a significant variation in colour, though only the rough surfaces displayed an appreciable change in visual appearance (Table 6). By way of comparison, stain resistance was characterised (UNE-EN ISO 10545-14) for green stain and olive oil agents, and by exclusively applying cleaning procedure A (hot running water and damp cloth), in all cases obtaining a significantly lower ΔE, which implied that the standardized test did not reproduce dirt retention in these work environments.

Surface	Actual retention		ISO 10545-14		Real+cleaning with brush	
	ΔE	Visible	ΔE	Visible	ΔE	Visible
Glossy smooth	1.53	NO	0.21	NO	1.36	NO
Satin smooth	1.49	NO	0.28	NO	0.36	NO
Satin embossed	1.83	NO	0.97	NO	1.21	NO
Rough smooth	5.09	YES	0.89	NO	2.31	NO
Rough embossed	11.94	YES	7.34	YES	8.51	YES

Table 6 *Results of change in colour of surfaces.*

Under real conditions, dirt retention occurs gradually, tending to stabilize at a maximum level, which depends on the type of cleaning used in facility maintenance (Figure 9). In the case studied, this was limited to the use of a mop and water with detergent.

To determine the maximum permanent retention which would have been achieved with more energetic cleaning methods, the pieces were hand cleaned with a stiff bristle brush. As can be seen, with the exception of the embossed rough surface, the rest of the ceramic flooring could be properly maintained using suitable cleaning methods.

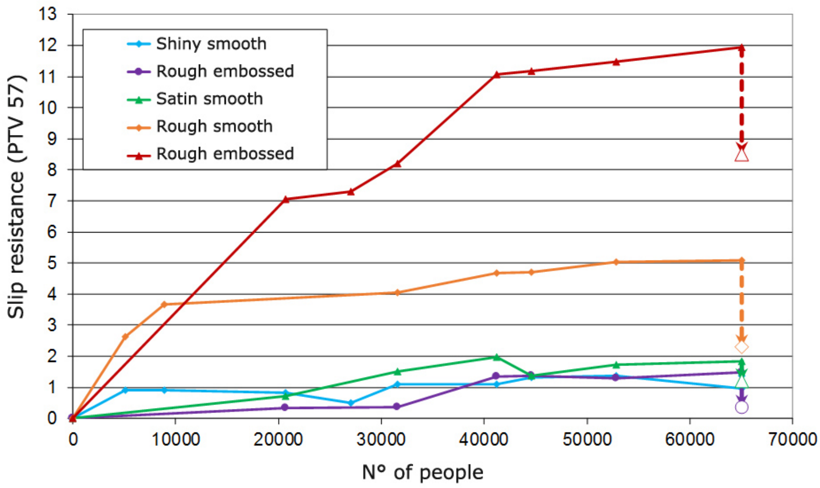


Figure 9 *Evolution of stain retention.*

Given that there is evidence that some cleaning systems can modify floor surface texture, in most cases reducing its contribution to slip resistance [9, 10, 11], it is planned to continue the present study by analysing the changes caused by the different mechanical cleaning systems commonly used in these work environments.

6. SELECTION OF FLOORING-FOOTWEAR COMBINATION

Unlike the regulations in the footwear sector, in which a single test method is available in addition to a classification which provides information about their performance in contamination with water (SRA) or greasy liquids (SRB), different test methods, which unfortunately show no correlation between each other, could be used for the selection of floorings.

In the following figures, the results obtained with the different types of footwear (in boxes) are presented compared to the results of the commonly used test methods for flooring with water contamination (Pendulum BOT 3000) and oil contamination (Ramp with Leipzig V73-SP footwear). By way of reference, the values of the requirements or classifications associated with each of the test methods have been included (dotted lines).

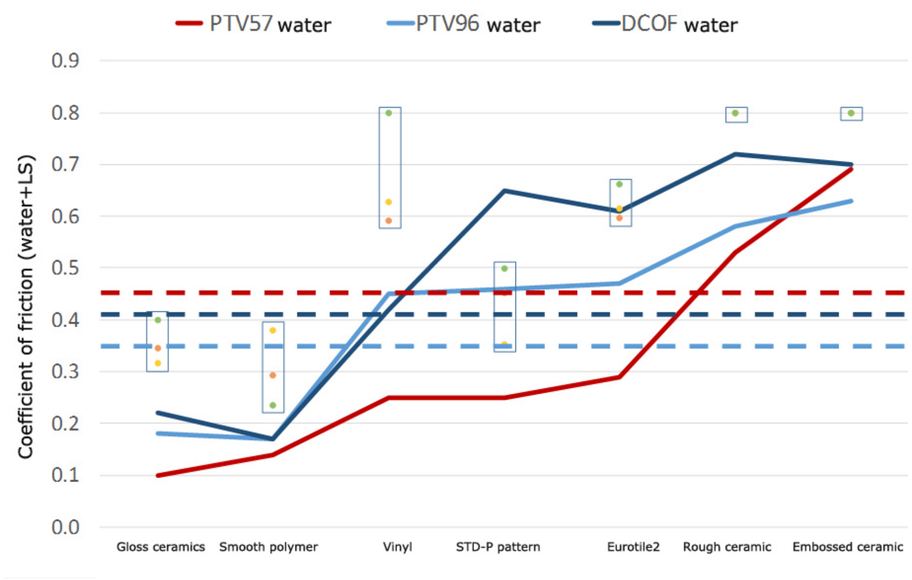


Figure 10 *Comparison with SRA footwear and water contamination.*

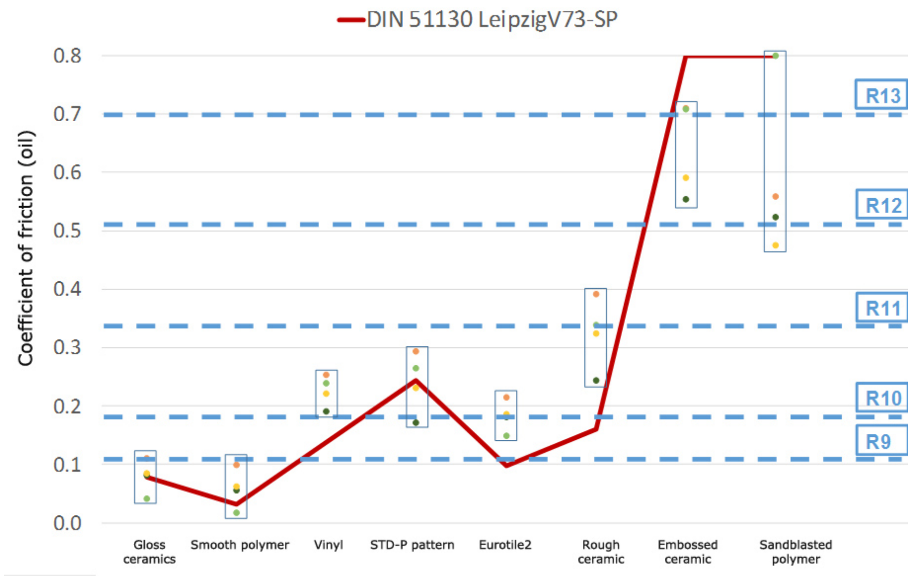


Figure 11 *Comparison with ramp test with oil.*

In the case of water contamination, the selection of floorings based on the specifications for the pendulum test is excessively conservative, especially if the soft rubber slider (PTV57) is used. As can be seen, with the exception of glossy smooth surfaces, most floorings allow sufficient available friction if they are used in combination with class SRA occupational footwear.

For environments susceptible to greasy liquid contamination, surfaces with an embossed texture should be selected, given that rough surfaces will present a gradual decrease in non-slip performance. In these cases, the use of specific cleaning methods for proper maintenance should also be assessed.

7. ACKNOWLEDGEMENTS

This project has been co-financed by the IVACE and the ERDF Funds, within the ERDF Operational Program of the Valencian Region 2014-2020 in the call for grants directed to Technological Centres of the Valencian Community.

The PORCELANOSA Group has taken part in the project, collaborating in the obtainment of ceramic surface prototypes. We should also like to thank PANTER and DIAN for their collaboration in the provision of the footwear used in this study.

8. REFERENCES

[1] Estadística de Accidentes de Trabajo. Ministerio de Empleo y Seguridad Social

[2] Equipos de protección individual. Calzado. Método de ensayo para la determinación de la resistencia al deslizamiento. UNE-EN ISO 13287:2013.

[3] Predicting slips and falls considering required and available friction. James P. Hanson, Mark S. Redfern and Mainak Mazumdar. ERGONOMICS, 1999, VOL. 42, NO. 12, 1619-1633

[4] W.R Chang, W.R, M.F. Lesch, C.C. Chang, and S. Matz (2015). "Contribution of gait parameters and available coefficient of friction to perceptions of slipperiness". Gait & Posture, 41, 288–290

[5] R. Bowman (2016). Can we develop slip resistance metrics that ensure appropriate tile selection? 14th World Congress on Ceramic Tile Quality

[6] R. Bowman, G. Silva, M. Engels, E. Astrachan. (2102) Slip resistance –Planning for a green future. 12th World Congress on Ceramic Tile Quality

[7] R. Mills, R.S.Dwyer-Joyce, M.Loo-Morrey. The mechanisms of pedestrian slip on flooring contaminated with solid particles. Tribology International 42 (2009) 403–412

[8] Muñoz, A., G. Silva, R. Domínguez, J. Gilabert, M. López, and M.C. Segura (2014). "Analysis of the life span of flooring slip resistance performance". 13th World Congress on Ceramic Tile Quality

[9] S. Derler ⇑, R. Huber, F. Kausch, V.R. Meyer (2015). Effectiveness, durability and wear of anti-slip treatments for resilient floor coverings. Safety Science, Volume 76, July 2015, Pages 12-20.

[10] Strautins, C., Sustainable slip resistance: An opportunity for innovation, (2008) 10th World Congress on Ceramic Tile Quality, Castellon, Spain, Vol. 3, P.BC 381.

[11] M. Engels (2016). New practice-oriented testing possibilities regarding the durability of slip resistance and cleanability 14th World Congress on Ceramic Tile Quality