RESEARCH INTO THE CHARACTERISTICS OF WELL-PERFORMING SURFACES IN CURRENT METHODS FOR EVALUATING SLIP RESISTANCE

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1. INTRODUCTION

The low slip resistance of pedestrian surfaces is frequently pinpointed as the factor responsible for accidents and falls. Consequently, for areas where the risk of slipping is critical, floor surfaces are made with characteristics that increase their coefficient of friction (COF). Despite much research, there is no universal solution to this problem, largely due to inaccuracies in the methods currently used to estimate the likelihood of accidental slipping [1]. In addition, different types of COF measuring equipment evaluate and interpret surface characteristics differently, which can lead to contradictory results [2]. However, in order to sell their products on diverse markets, manufacturers need to have them approved according to the standards required by each different market. In such a scenario, the objective of this study was to try to identify what characteristics ceramic flooring surfaces need to have to ensure they perform well when testing methods differ.

2. MATERIALS AND METHODS

A selection was made of commercially available products with a variety of surfaces: glazed and unglazed, polished, with grits, glossy and matt, smooth and asperous to the touch, and with undulations or slight relief. The roughness of the samples was characterised with a mechanical profilometer (cut-off value: 2.5 mm). The profiles obtained were used to calculate the roughness quantification parameters, such as the number of irregularities, the format, amplitude and spacing between them. This data was correlated with the dynamic coefficient of friction estimated by three test methods: pendulum friction, Tortus and BOT-3000. The same correlations were made for a subset of samples. Surfaces with relief, undulations or a very heterogeneous design were discarded from the initial set in an attempt to isolate the effect of the roughness variable in slip resistance.

3. RESULTS AND DISCUSSION

In Table 1, the methods can be seen to produce a clear divergence of results and, in response to the range of surfaces evaluated, slip resistance varies greatly too. In Table 2, the correlation coefficient between these results and the roughness parameters under study is seen to be low. This is because the surfaces differ in terms not only of their roughness but also of their relief and undulation. Therefore, it is difficult to draw linear correlations between COF/PTV [Pendulum Test Values] and parameters that describe a single aspect of the product's surface. Furthermore, slip resistance can be overestimated for very smooth surfaces (adhesion effect), or underestimated for rougher surfaces or surfaces with relief (loss of contact with the slider during measurement).

COF	1	2	3	4	5	6	7	8	9	10	11	12
TORTUS	0,52	0,45	0,36	0,38	0,37	0,37	0,35	0,42	0,60	1,00	0,77	0,97
BOT	0,43	0,60	0,24	0,29	0,34	0,38	0,26	0,45	0,74	0,80	0,70	0,78
PENDULUM	17	42	20	13	17	25	15	32	44	60	52	80

***Table 1**. Coefficient of friction (Tortus and BOT) and PTV (pendulum) for the surfaces under study*

Group 1	Ra	Rq	Rz	Rc	Rt	Ry	Rp	Rpm	Rv	Rvm	R3z	R3y	Rk	Rpk	Rvk	Δq	Ir
Tortus	0.41	0.4	0.29	0.14	0.32	0.46	0.26	0.41	0.37	0.49	0.47	0.55	0.45	0.1	0.25	0.7	0.62
Bot	0.38	0.39	0.27	0.14	0.32	0.47	0.31	0.46	0.3	0.42	0.57	0.65	0.43	0.14	0.22	0.66	0.47
Pendulum	0.53	0.54	0.42	0.2	0.49	0.65	0.42	0.6	0.52	0.64	0.74	0.82	0.6	0.21	0.39	0.89	0.78
Group 2	**Ra**	**Rq**	**Rz**	**Rc**	**Rt**	**Ry**	**Rp**	**Rpm**	**Rv**	**Rvm**	**R3z**	**R3y**	**Rk**	**Rpk**	**Rvk**	**Δq**	**Ir**
Tortus	0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.96	0.97	0.95	0.96	0.97	0.96	0.96	0.93	0.94
Bot	0.96	0.96	0.96	0.97	0.96	0.96	0.98	0.98	0.92	0.94	0.97	0.97	0.96	0.97	0.95	0.95	0.86
Pendulum	0.98	0.98	0.98	0.95	0.99	0.98	0.97	0.97	0.99	0.99	0.96	0.98	0.98	0.96	0.99	1	0.97

Table 2. *Correlation coefficient R^2 between slip resistance assessed by the methods under study and roughness parameters for the initial group (Group 1) and the subset of samples (Group 2)*

However, for the subset under study, Group 2, high correlations were found in all the methods for parameters mentioned in the literature and others that are not. This means that when other variables that affect friction are set, the roughness associated with those parameters can be controlled to increase slip resistance in those methods. Parameters R are different ways of quantifying profile amplitude and when that amplitude is controlled to increase a parameter, others tend to increase simultaneously. ΔQ is indicative of the inclination of the profile, while roughness index, Ir, is usually higher in profiles that have numerous peaks and valleys. Thus, the conclusion is drawn that profiles that are likely to increase COF/PTV are the ones with numerous high and steep peaks, as Figure 1a illustrates. Figure 1b shows a profile with similar amplitude due to the undulation of the surface but which is smooth and glossy (visual observation). However, the profilometer may interpret that amplitude as amplitude of roughness, since the boundary between the two is not clearly defined. Thus, high readings were obtained in the roughness parameters for that surface. Nevertheless, it returned lower slip resistance than expected given the values of the parameters. This is one case in which, when surfaces in which factors apart from roughness affect the friction coefficient are compared, no good correlations are returned between slip resistance and roughness parameters. For that reason, that particular surface was one of the ones omitted from Group 2. Other samples also reduce the correlation, but because their slip resistance is higher than expected given their roughness parameters, they form roughness profiles like the one in Figure 1a (numerous, sharp peaks) but superimposed on a relief. This increases the ability to anchor the foot securely but also the space to accommodate fluids, thus avoiding the formation of oily films.

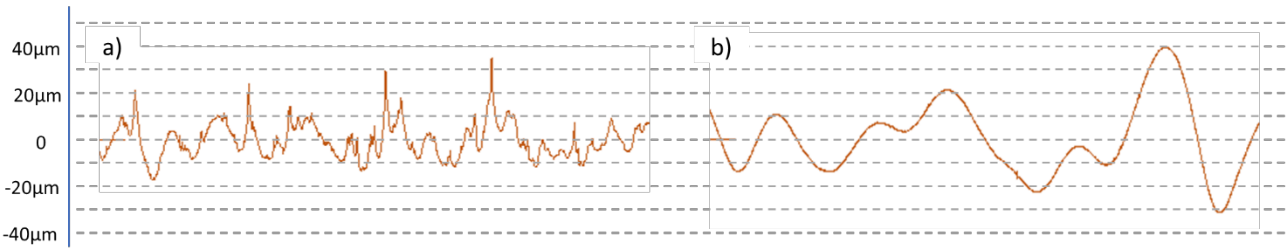

***Figure 1**. Roughness profiles with similar amplitude obtained for the samples under test*

4. CONCLUSIONS

For a subset of samples used in an attempt to assess, individually, the effect of roughness on slip resistance, linear correlations were found between the results of the three assessment methods studied and certain roughness parameters. It is concluded that roughness plays a highly relevant role in defining slip resistance and, when other variables are fixed, it is possible to control those aspects when the product is being manufactured in order to comply with the requirements of different sets of regulations. In this regard, roughness profiles with numerous steep and high peaks should be sought.

5. REFERENCES

[1] SILVA, G., et al. Combinaciones Optimizadas de Pavimento Cerámico y Calzado para Entornos Laborales – Qualicer Proceedings 2018

[2] FONG, D.T. et al. Greater toe grip and gentler heel strike are the strategies to adapt to slippery surface. Journal of Biomechanics, v. 41, p. 838–844, 2008.