Multiple aspects of comparing surface properties of ceramic tiles regarding slip resistance

Anita Terjek [1, a *]

[1] ÉMI Nonprofit Llc., Dózsa György út 26., 2000 Szentendre, Hungary

[a]aterjek@emi.hu

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Abstract. The objective of this study was to determine the affecting factors that can possibly change slipperiness of flooring. Laboratory slip resistance tests were conducted under different surface conditions. Two different methods were used to measure 6 different ceramic tiles. This article has its focus mainly on the required security and its quantification during the service life of floor coverings. Slip resistance of ceramic tiling can change with use. It is worth to investigate the effect of cleaning agents on slipperiness of floors, because it could be more dangerous when the cleaning process is in progress, so the surface is still in wet state or partly covered by liquid. This paper makes a comparative analysis on the different measurement methods and sliders that rub against the surface. In case of public and residential buildings slip resistance and surface roughness associated with cleanability, all have influence on safety in use and durability. The results showed that the perceived surface roughness parameters could be used as indicator of slipperiness and supplement objective measurement of this performance.

Introduction

Floor covering is responsible for ensuring the quality, mechanical properties of flooring regarding its intended use, so it is unavoidable to know if it will fit for its purpose. Beside this also aesthetic appearance (color, surface texture, decoration, etc.) is an important factor choosing the appropriate tile from a wide range of flooring materials available on the market.

The most important step in design is to specify precisely the influence which the structure is exposed to and to define the essential requirements, in order to choose the most suitable flooring. That is why the use of appropriate design and construction technology is significant. The article from this aspect deals with ceramic tiles, the mostly chosen material for flooring solutions in practice. These products are the common decoration material for floors and walls of not only residential houses, but shopping malls, business, sport and wellness centers, as well as hospitals or laboratories.

However buildings may have an impact on the requirements of products, floorings made of ceramic tiles are subjected to various stresses for both internal and external usage. The top layer of the floor - covering or coating – gets directly those various effects derived from the function of areas and stress due to the processes of production and delivery. Therefore it is so important that the declaration of performance of a ceramic tile shall express all the performance related to the relevant essential characteristics laid down in the EN 14411 [1] harmonized standard.

In order to ensure that the declaration of performance is accurate and reliable, the performance of the construction product should be assessed and the production in the factory should be controlled in accordance with an appropriate system of assessment and verification of constancy of performance of the construction product [2]. Obviously from general criteria described in Construction Products Regulation (EU) No 305/2011 (CPR), safety and accessibility in use raises more questions, especially in the subject of slip resistance.

In floors lying on the ground insufficient waterproofing of the structure can cause the separation of the adhesive layer and thus decrease in homogeneity and load bearing capacity. The fragmentation of ceramic tiles affects the safety in use as well [3].

Hence surface properties of ceramic tiling such as cleanability, slip resistance and its negative changing is an important research topic. In this context surface roughness measurements are not negligible. In addition to the technological requirements the entire structure of the floor layer also affects the tested characteristics mentioned in this article. Taking into account the effect of liquids is also important in terms of use and proper operation. The suitable design of a drainage system can ensure dry pedestrian areas (Fig. 1).

Fig. 1: *Example of a shower channel application (Gyuro, Hungary)*

The effective drainage of water from the floor can allow to avoid slips and falls on the surface. This is also significant because for certain functions slipping cannot be prevented by using anti-slip coating itself, such as in swimming pools, industrial laundries, commercial kitchens, etc. The moisture or water exposure can attack floorings from the soil below and from above when the surface of the floor gets altered water load during use [4].

Experimental Procedures

Six different type of ceramic tiles were selected showing diversity in material, texture, and thus in the behavior. There were 3 glazed (G) and 3 unglazed (UG) dry-pressed tiles with different surface roughness. Figure 2 shows the images of tested ceramic tiles.

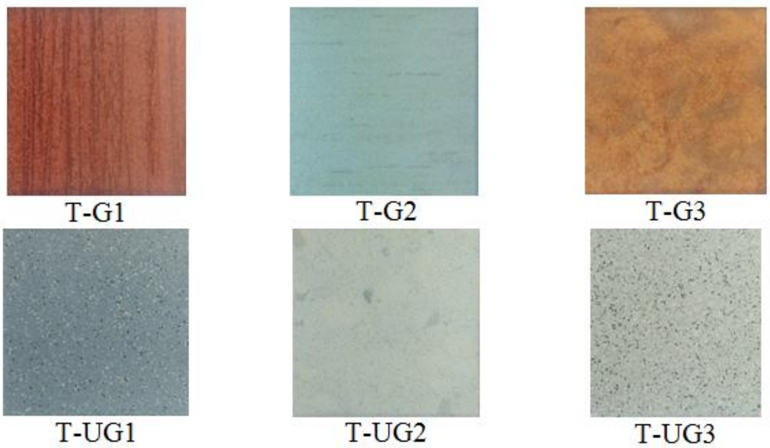

Fig. 2: *Images of tested ceramic tiles (representing a 5 cm × 5 cm surface)*

For determining friction a precise examination is necessary, which approximately simulates the physical forces, the process of walking, and can be repeated at any time under the same conditions. Until now, numerous comparative studies of friction measurement devices and methods have been published, examining the validity, repeatability, precision and consistency [5].

In this study we decided to investigate the correlation between 2 common slip resistance methods focusing on the size of sliders and the difference in units. We also would like to determine surface roughness as an important contributor to slip resistance. The experiment was conducted in the laboratory of EMI Nonprofit Llc. in Budapest, Hungary.

Pendulum Test Value. Skid-resistance tester (SRT), shown in Fig. 3 is a portable device described in the standard EN 13036-4 [6]. Operating by the principle of the Charpy pendulum, on the swinging arm the slider is allowed to fall from a certain angle, and it rubs against the surface that is being tested. The measured pendulum test value (PTV) is proportional to the absorbed potential energy of the slider.

Fig. 3: *Skid Resistance Tester*

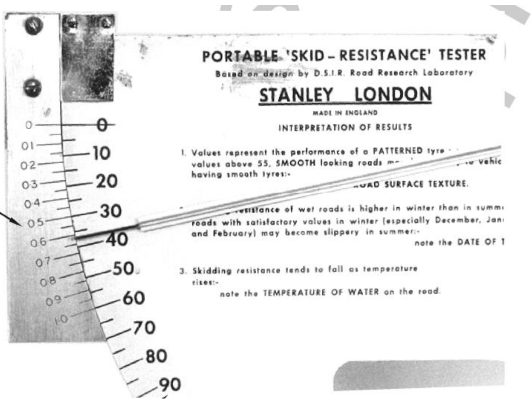

Fig. 4: *Unit scale of Skid Resistance Tester*

Due to the fact that adhesion between the surface and the slider can be altered when covered with liquids, measurements taken in both wet and dry state are significant in this case, and also the size of slider was taken into consideration. There are two type of slider; the wide slider is set to traverse a surface over a fixed length of 126 ± 1 mm, while in the narrow slider case the nominal sliding length is 76 mm. Therefore the reading of PTV differs. For measurement with the wide slider, unit scale C (Fig. 4) is used that is marked from 0 to 150 at intervals of five. In this mode of operation the PTV is given directly. For measurement with the narrow slider PTV may be estimated by calculation, it can vary from 0,0 to 1,0 as described in unit scale F (Fig. 4) with intervals of 0,05 units.

Different surface conditions were tested, which were dry and wet with both narrow and wide slider. For the dry conditions, slip resistance measurements was conducted on clean and dry tiles. For the wet conditions, the amount of clean water needed for replenishment was according to the standard.

As a matter of fact, required or specified slip resistance can be maintained by frequent effective cleaning with appropriate detergent and cleaning tools. Therefore surfaces of these tiles were further examined by applying sodium hypochlorite (5% NaOCl solution diluted with water in 1:5 volume proportion) as wetting agent. In most domestic and commercial applications NaOCl is frequently used as a disinfectant or bleaching agent because it has destaining properties. Among other applications, it has also been used in some laundry detergents. NaOCl dissolved in water is often the disinfectant of choice in cleaning surfaces in hospitals [7].

The purpose was to evaluate the risk of slipping and falling in such an environment, so five additional readings were recorded for each floor tile wetted with NaOCl solution. In order to get adequate correlation, we measured PTV with wide slider.

Coefficient of Friction. The coefficient of friction measurements were conducted using Floor Slide Control 2000 Print (Fig. 5), which is an example of equipment used for floor friction test both in laboratory and on site. It operates on a similar principle as described in CEN/TS 16165 [8], so it travels across the surface pulling the measuring glider and directly calculates the coefficient of friction (COF).

Fig. 5: *Floor Slide Control 2000 Print*

For wet measurements, a sponge filled with about 5 cm^3 of water is used to wet the surface in front of the gilder. Once the measurement has been started, COF can be read from the display and measured values can also be printed out. Five readings were recorded for each floor tile on a wetted measuring path of 300 mm.

Surface Roughness. Determining surface roughness of ceramic tiles is significant. The measure of the texture of a surface is quantified by the vertical deviations of a real surface from its ideal form. Detecting unevenness of the surface measurements were performed by Surftest SJ-301 surface roughness-meter (Fig. 6) using the differential inductance method.

Fig. 6: *Surftest SJ-301 surface roughness-meter*

A very small (scale of µm) tip radius of diamond stylus is moved in contact with a sample for a specified distance and contact force while scanning the surface. This portable device has a wide measurement range of 350 µm (-200 µm to + 150 µm) and can provide 19 analysis parameters. Results can be printed out with the graphical representation of surface profiles. The approach is to measure and analyze the surface texture, so a filtered roughness profile is used for this evaluation. For representing the surface roughness, in this study 2 roughness parameters (arithmetical mean deviation (R_a) and the maximum height of the assessed profile (R_z)) were chosen for the evaluation according to standard EN ISO 4287 [9].

Experimental Results

In Table 1 results of slip resistance (average of 5 readings on each tile) are presented.

Table 1. *Result of slip resistance tests measured on ceramic tiles*

Sample ID.	Pendulum test value measured with wide slider			Pendulum test value measured with narrow slider		Coefficient of friction
	PTV dry	PTV wet, water	PTV wet, solution	PTV dry	PTV wet, water	COF wet
T-G1	58	21	20	0.63	0.17	0.62
T-G2	58	19	16	0.59	0.12	0.61
T-G3	81	64	60	0.95	0.39	0.69
T-UG1	72	55	48	1.00	0.25	0.79
T-UG2	70	29	28	1.00	0.15	0.47
T-UG3	76	49	45	0.90	0.20	0.78

It was pointed out that it is difficult to draw correlations for the assessment of the individual slip resistance test methods because of the difference not only in the design of these equipments, but in the size of various sliders in contact with the surface. For this reason tests have been performed on ceramic tiles characterized by different surface texture to assess the interaction of slipperiness and surface roughness. Two roughness parameters were measured on the surface of each samples and Table 2 shows the average of 5 measurements.

Table 2. *Result of surface roughness of ceramic tiles*

Sample ID.	Arithmetical mean deviation (R_a) [μm]	Maximum height of the assessed profile (R_z) [μm]
T-G1	0.91	5.43
T-G2	0.63	4.41
T-G3	4.00	20.85
T-UG1	1.93	12.66
T-UG2	2.99	18.40
T-UG3	2.23	12.91

Discussion and Conclusions of Results

Hence, slipperiness is always interpreted relatively, the risk of slipping depends not only on the pedestrian behavior and the type of footwear, but also the condition (dry or wet state) of the surface should be considered as an influencing factor. There is a significant decrease in slip resistance when surface gets in contact with a lubricant. Fig. 7-8 show the change of average values of slip resistance test performed by using SRT on ceramic tiles samples.

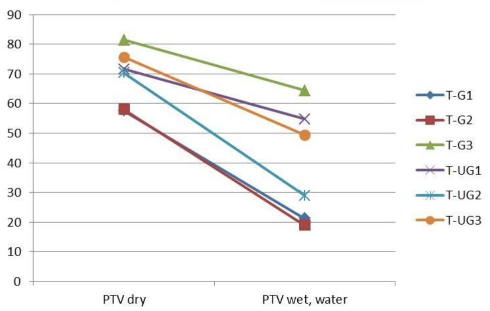

Fig. 7: *Change in PTV measured with wide slider*

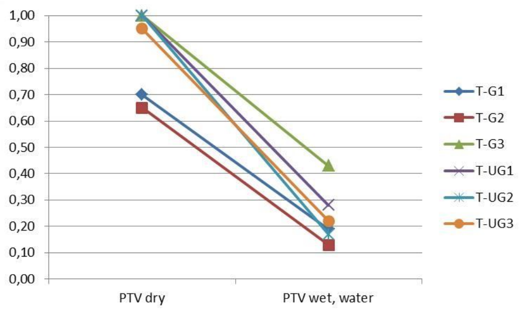

Fig. 8: *Change in PTV measured with narrow slider*

Results received by using both wide and narrow slider follow this pattern, so the distribution of individual values for all the six samples is illustrated in Fig. 9. As it can be seen coherent pairs of values are presented. Measurements of a wet surface eventuate lower results, thus concentrating on the bottom part of the chart.

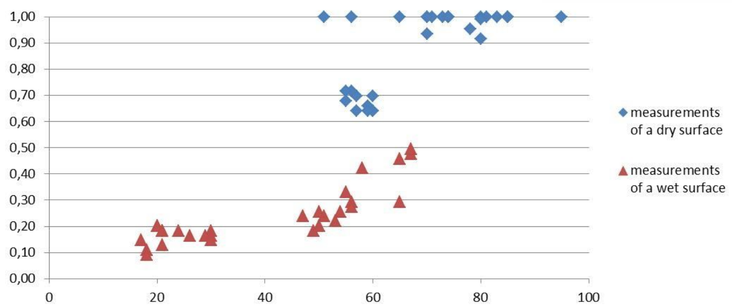

Fig. 9: *Distribution of individual PTV*

According to the EN 13036-4 standard measurements with wide slider read on unit scale C is interpreted in the range of 0-150, while using narrow slider results vary from 0.0 to 1.0 on unit scale F. Because of this deviation in range, PTV measured with narrow and wide slider could not be explicable directly. Each value was converted into the other in order to correlate them (Fig. 10-11).

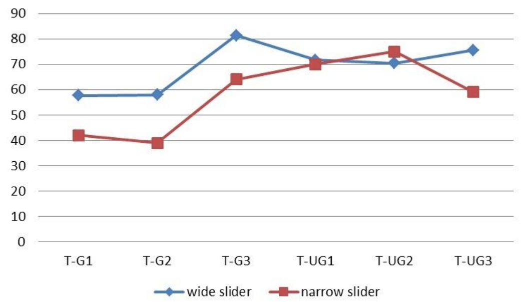

Fig. 10: *Comparison of PTV measured on dry surface*

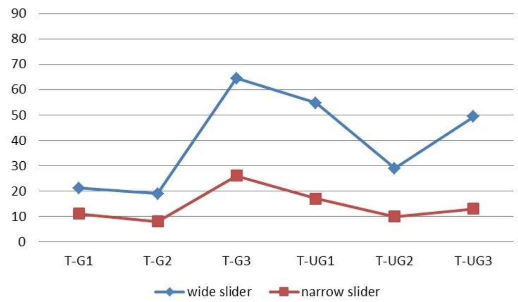

Fig. 11: *Comparison of PTV measured on wet surface*

In that case when results are represented according to unit scale F, diversity of PTV is not distinguishable in dry state (Fig. 12-13). These results are measured with wide slider on samples with different surface properties Measurements giving higher values than 60 PTV can only be represented as 1.0, thus 4 samples might be considered having the same surface texture from this aspect.

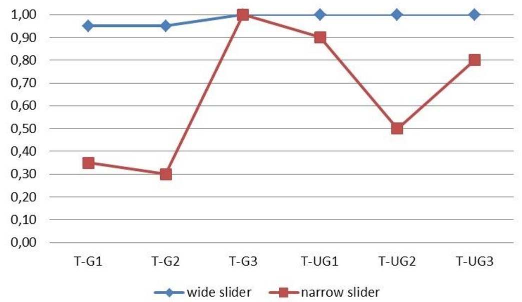

Fig. 12: *Comparison of PTV measured on dry surface*

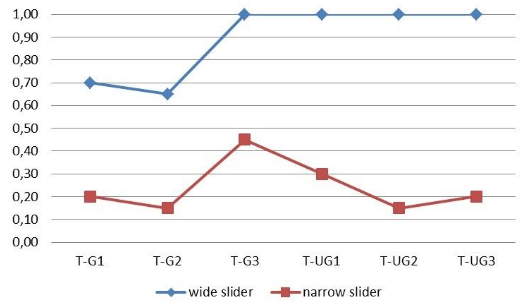

Fig. 13: *Comparison of PTV measured on wet surface*

In-situ slip resistance testing also shows that there is non-negligible decrease in PTV measured after wetting the same surface. As a consequence of the unity in dimensional interpretation, PTV (represented according to unit scale F) and coefficient of friction are correlated directly. The variability of results regarding all measurements on each sample can be seen on Fig. 14-15.

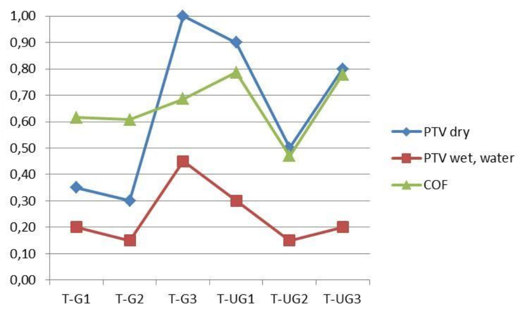

Fig. 14: *Correlation of different slip resistance test results by samples*

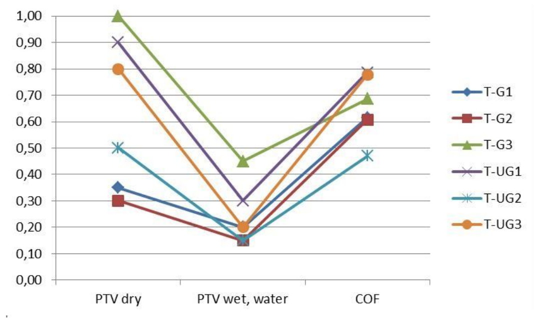

Fig. 15: *Correlation of different slip resistance test results by methods*

Concerning PTV of wetted surface and COF, both methods require sufficient water to determine slipperiness. However there is a significant difference among these results. Classifying ceramic tiles based on only COF may lead to inaccurate evaluation. Comparing the obtained test results (Fig. 16), a linear relationship (Eq. 1) was found between the two parameters that can be described by

$$COF \approx PTV_{wet} \times 3. \tag{1}$$

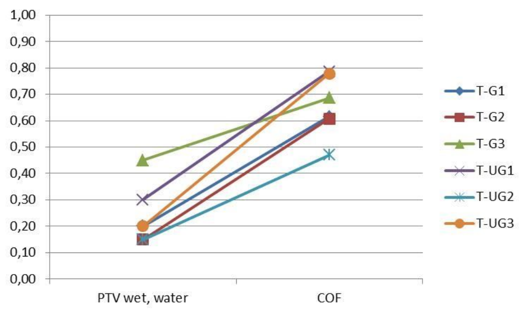

Fig. 16: *Comparison of PTV of wetted surface and COF*

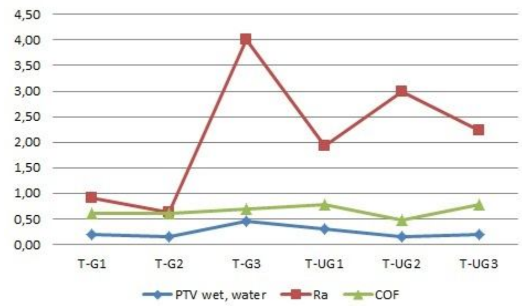

Fig. 17: *Relationship between R_a, COF and PTV of wetted surface*

In the case where only the coefficient of friction might be a measure, high values might mislead. As a matter of fact, surface roughness can be an indicator of the behavior of the different texture, so it can quantify surface properties. Fig. 17 represents the relationship between arithmetical mean deviation (R_a) and the above mentioned slip resistance values (PTV of wetted surface and COF).

Risk of slipping on flooring is mostly affected by the presence of contamination. For ceramic tiles, establishing an effective cleaning is important. The type of contamination will influence the treatment and the cleaning frequency. Required or specified slip resistance can be maintained by frequent effective cleaning with appropriate detergent and cleaning tools. We examined earlier how the cleaning regime effects the change in slipperiness and roughness of ceramic tiles (deterioration in the surface was observed affecting the surface quality). For further consideration we measured PTV (Fig. 18) by using NaOCl solution as wetting agent.

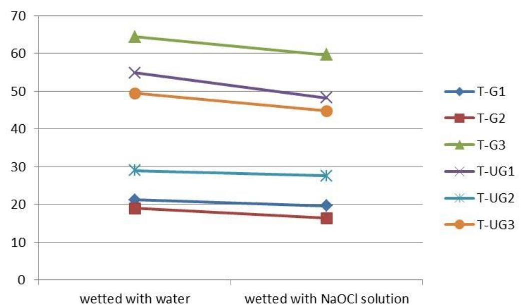

Fig. 18: *Change in PTV by using NaOCl solution*

Conclusions

Regarding the research and application of ceramic tiles there is a great importance of defining precisely the performance in order to install the right floor covering for the right environment. While many tiles rapidly lose significant slip resistance if the surface is covered with water, maintenance is a key factor predicting acceptable long working life.

Accidents are affected greatly by the surface structure of floors and working with slippery materials. The slipperiness of flooring depends on surface properties, reaction and adaptation of pedestrian, quality of floor construction, and at last maintenance work. Each manufacturer has a technical guideline that determines frequency and intensity of cleaning taking into account the aspects of slip resistance, basically depending on the degree of contamination. Cleanability, in the function of measuring surface roughness, has a major role in terms of service life and durability of floor structure.

Our experiences show that multiple testing is essential because of the complexity of defining and measuring slip resistance. The alteration between these results also plays an important role in the uncertainty of evaluation of flooring materials in different stages. For the six ceramic tiles chosen in this study, a linear relationship between PTV of wetted surface and COF was defined. It was examined that after measuring PTV by applying NaOCl solution changes in the surface occurred, so the type of detergent can influence slipping properties of ceramic tiles. Results show that surface roughness can give a qualitative comparison to the assessment of slip resistance.

When assessing the performance of a construction product, account should be taken relating to the use of the product during its entire life cycle from health and safety aspects. In conclusion to give satisfactory service for ceramic tiles, it is necessary to be selected and installed competently, and to receive appropriate initial treatment, protection and maintenance.

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